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**Determination of Harmful Quantities and
Rates of Penalty for Hazardous
Substances. Volume II**

Battelle-Northwest, Richland, Wash Pacific Northwest Lab

Prepared for

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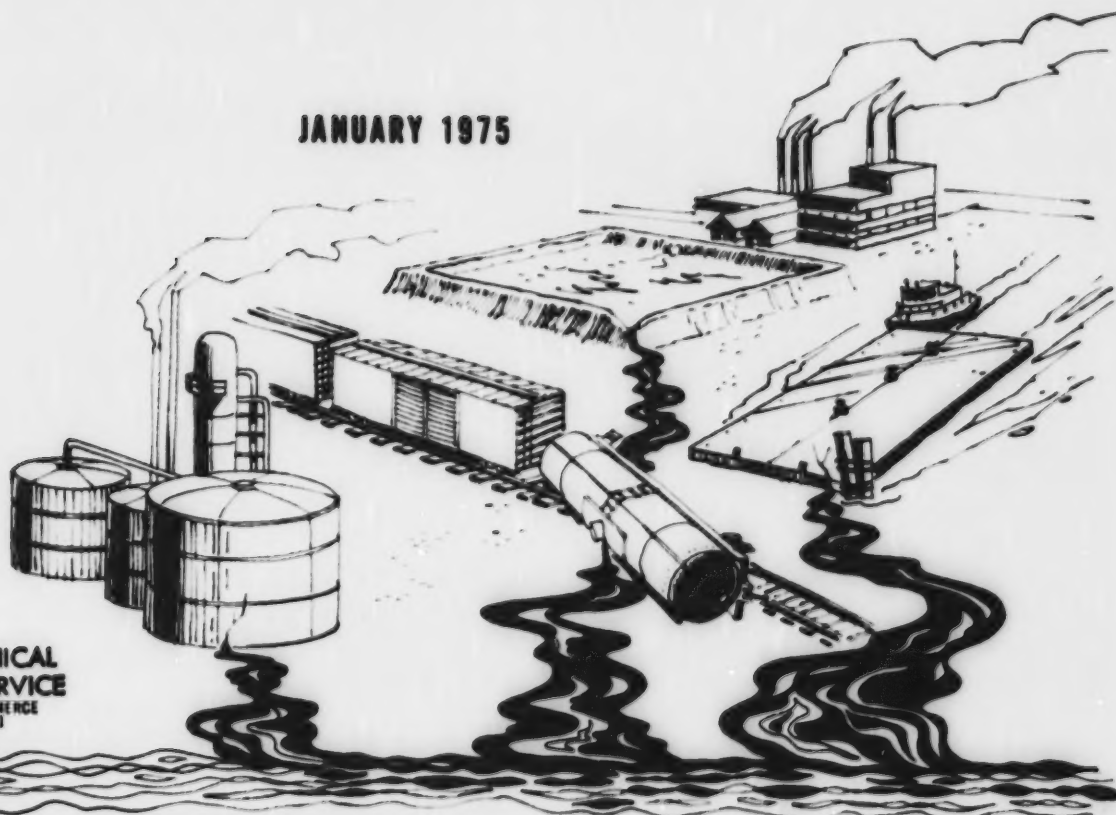
FINAL REPORT

VOLUME II - TECHNICAL DOCUMENTATION

**DETERMINATION OF HARMFUL QUANTITIES AND
RATES OF PENALTY FOR HAZARDOUS SUBSTANCES**



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ENVIRONMENTAL PROTECTION AGENCY • OFFICE OF WATER PLANNING AND STANDARDS

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by

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OCTOBER 1974

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FOREWORD

This report was initiated by the Environmental Protection Agency to gather additional information and to complete several concepts developed by the technical staff of the Agency. This report is one of the series dealing with hazardous materials and the prevention and/or removal of spills of these materials into or upon the navigable waters of the United States. The methodologies were determined to be necessary to provide a technical basis for the development of regulations under Section 311 of Water Pollution Control Act as amended in 1972 (PL 92-500). This report is a result of several man years of work by the Government, industry, and the contractor. It should be understood that the methodologies explained here may be used in some modified form in regulations to be developed and/or revised as appropriate to implement Section 311.

This document should be regarded as a technical reference document which may be used as appropriate by this Agency and others primarily in the development of the regulatory control program for hazardous substance spills. The principal regulations for which these methodologies were developed are required to be promulgated under Section 311(b)(2)(B)(iv) and Section 311(b)(4) which require that penalty rates for nonremovable hazardous substances shall be prescribed and that quantities determined to be harmful to public health and welfare be identified. The other regulations as required by Section 311 dealing with hazardous substances involve: the designation and determination of removability; the determination of removal and mitigating methods; the determination of procedures and equipment for spill prevention; the determination of small facility spill clean-up liabilities; the determination of nonharmful quantities; and appropriate revision to the National Oil and Hazardous Substance Pollution Contingency Plan. This information is thought to be of use of assessing the environmental benefits and potential economic impacts in the development of regulations dealing with methods for removal and mitigation of hazardous substances and procedures and equipment for prevention of hazardous substance spills from transportation, production and use facilities.

At the time the project was conceived the Agency had participated in international hazardous material control negotiations and had gained considerable experience working with industry in the production, distribution and use of materials which may be designated as hazardous substances. Late in 1972 and early in 1973, it became the concern of this Agency that several alternative methods should be examined in detail to allow equitable regulatory development. This concern was keyed to be pending designation regulation which would list elements and compounds as hazardous substances.

It is anticipated that the information that has been gathered during this study which involved the National Hazardous Materials Conference in San Francisco, August 1974, and the Regulation Symposium in Washington, DC in October 1974 will be utilized in part in the development of regulations to be published in the Federal Register. Once the regulations are promulgated, going through the process of Advance Notice of Rule Making, Proposed Rule Making, and Final Promulgation, the program will be implemented nationwide. This program implementation is anticipated to be in conjunction with the United States Coast Guard and to be implemented at the EPA Region and Coast Guard District Level. It is further anticipated that areas for the Administrator's discretion in evaluating penalties may be established as appropriate through EPA Guidelines and/or Enforcement Regulations formulated by this Agency.

Particular thanks should be expressed to the primary authors of this Report with special emphasis to acknowledge the cooperation provided by the chemical manufacturing industry, the chemical transporting industry and others who supplied basic information upon which this study is built. An individual appreciation is expressed to Dr. Allen L. Jennings of the Hazardous and Toxic Substances Branch for his technical participation and enthusiasm in seeing this job completed. Others who helped in the review and editing for EPA included Dr. Gregory Kew, Messrs. Robert Sanford, James Cating, and Charles Gentry. It should be recognized that this project was possible due to the foresight in planning, funding, and the staff assistance of Messrs. Walter Miguez, Robert Suzuki, John Cox, and others of the Division of Oil and Special Materials, without whose help this project would have been impossible.

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I. INTRODUCTION

Pollution resulting from the spillage of oil and hazardous materials has emerged as a major national problem. It is presently estimated that some fifteen thousand such spills occur annually in the navigable waters of the United States,¹ of which more than three thousand involve non-oil materials.² These spills range in size from small quantities to millions of gallons³ and threaten many important waterways.

Recognizing this, the Congress has declared in Section 311(b)(1) of the Federal Water Pollution Control Act Amendments of 1972, that:

".... it is the policy of the United States that there should be no discharges of oil or hazardous substances into or upon the navigable waters of the United States, adjoining shorelines, or into or upon the waters of the contiguous zone."

Pursuant to this policy, Section 311 requires the formulation of seven distinct regulations:

- 1) The designation of elements and compounds as hazardous substances [Section 311(b)(2)(A)] in order to establish the list of materials other than oil which will be subject to the remaining six regulations;
- 2) The determination of removability of hazardous substances [Section 311(b)(2)(i)] in order to group designated hazardous substances into removable and non-removable categories for the purpose of subsequent penalty determinations;

¹Thompson, C. H. and P. R. Heitzenrater. "The Environmental Protection Agency's Hazardous Material Spill Program," presented at the American Institute of Chemical Engineers Workshop, Charleston, WV, October 27-29, 1971.

²Wilder, I. and J. Lafornera. "Control of Hazardous Material Spills in the Water Environment," Water and Sewage Works, 119: 1: 82, 1972.

³Thompson C. H. and K. E. Biglane. "Oil and Hazardous Materials--The Chemical Industry's Liability or Asset?", presented to Chemical Markets Research Association in Chicago, IL, February 24, 1971.

- 3) The establishment of rates of penalty for spillage of hazardous substances [Section 311(b)(2)(B)(iv)] in order to prescribe the penalties to be assessed for spillage of non-removable hazardous substances;
- 4) The designation of harmful quantities [Section 311(b)(4)] in order to specify a quantity such that spillage exceeding that amount must be reported by the responsible agent to avoid criminal prosecution for failure to notify;
- 5) The establishment of small facilities liability limits [Section 311(f)(2)] in order to provide for the designation of certain small facilities as low hazard potential spill sites eligible for commensurately lower liability rates;
- 6) The specification of methods and procedures for removing spilled hazardous substances [Section 311(J)(1)(A)] in order to identify methods and procedures to be employed in removing spilled materials consistent with maritime safety and navigation laws; and
- 7) The specification of spill prevention measures [Section 311(J)(1)(C)] in order to identify procedures, methods, equipment, and other requirements pursuant to preventing discharges of hazardous materials.

Each of these elements addresses a facet of the overall hazardous substance spill problem in an attempt to stimulate and encourage spill prevention measures. Indeed, prevention has been clearly identified as the primary defense against damages resulting from hazardous substance spills.⁴ It is recognized, however, that spills can and will continue to occur⁴ and therefore provision must be made to minimize impacts in the event of these occurrences. This area of regulation also serves as a part of the preventive posture in that the financial resources required to remove hazardous substances after spills constitute an economic incentive to improve preventive measures.

Although none of the above regulations have been finalized, many preliminary steps in the formulation process have been taken. One major step has been the sponsorship of a

⁴Dawson, G. W., A. J. Shuckrow and W. H. Swift. "Control of Spillage of Hazardous Polluting Substances," U.S. Environmental Protection Agency, FOZ 15090, October 1970.

continuing interchange of ideas between responsible officials in the Environmental Protection Agency (EPA) and interested parties in the private sector in both a formal and informal context. Exchanges have also been maintained with other maritime nations through the Inter-Governmental Maritime Consultative Organization (IMCO). Supportive technical work has been provided by the EPA Office of Research and Development and has been directed primarily toward defining the scope of the problem, developing means for spill prevention, and the removal of spilled materials.

Two of the required regulations have been published in the Federal Register⁵ as advanced notices of proposed rule making. These are the regulations dealing with the designation of hazardous materials and the categorization of those materials into removable and non-removable groupings.

The technical documentation required for two additional regulations, those dealing with the designation of rates of penalty and harmful quantities is the subject of the research program reported herein. The objective of the program was to develop at least three separate approaches which could be used to derive harmful quantities and rates of penalty for any given non-removable hazardous substance. Four such methodologies were developed.

Each methodology is characterized by three distinct features: 1) the definition of substantial harm upon which the harmful quantity is based, 2) the economic rationale for the base rate of penalty, and 3) a means for varying rates of penalty based on the physical-chemical and toxicological properties of the material.

The first approach, the Resource Value Methodology, defines substantial harm as \$5,000 worth of environmental damage. That is, harm is substantial when water with a recreational and social value in excess of \$5,000 is degraded to levels impairing its value for those uses. Base rates of penalty are set at the value of the damage potentially resulting from a spill of a given material. Penalties are varied on the basis of the probable duration of adverse impacts and the physical-chemical properties which enhance or restrict movement of the material in the environment.

The second approach, the IMCO Methodology, employs the same basic definition of substantial harm and rationale for

⁵Federal Register, Vol. 39, No. 164, Part IV, August 22, 1974.

base rates of penalty as the Resource Value Methodology, but focuses on four groups of hazardous materials rather than individual materials. Each of the four categories is defined in accordance with the Inter-Governmental Maritime Consultative Organization (IMCO) system for hazardous cargo classification. Toxicological data representative of the category as a whole is employed to derive harmful quantities. Penalties are varied over one order of magnitude through use of adjustment factors designed to reflect the ability of a material to spread in the environment and exert its hazard potential.

The third approach offered, the Unit of Measurement Methodology, defines substantial harm for an IMCO grouping of materials indirectly through selection of a unit of measurement, sufficiently large to be associated with probable harm in the event of a spill. Similar quantities are selected for the remaining groups of materials through comparison of their relative toxicities. Penalties are varied on the basis of the persistence, volatility, solubility, and specific gravity of individual materials.

The final approach, the DOHM Methodology, defines substantial harm in a statistical manner by developing an idealized plug flow stream model and employing a flow rate selected from statistical data on stream flow in the United States. The base rate of penalty is equated to the estimated cost of prevention (the expenditure per gallon spilled which would have prevented the spill from occurring). Quantitative operators are employed to vary the rate of penalty by a factor of two as a function of the toxicity, degradability, and toxicity-to-solubility ratio.

The development work reported here was undertaken with four major boundary conditions specified. First, the resulting methodologies were to cover only the technical aspects of approaches to formulating the required regulations with the structure provided by Section 311. No attempt was made to modify the legislative mandate or explore policy and enforcement options. Second, Congress has specified the use of a civil penalty and, in so doing, has chosen a rationale of encouraging spill prevention practices rather than one of punitive damages. Indeed, it is acknowledged that a civil penalty is best designed to deprive an offender of economic advantage which noncompliance would otherwise have given him.⁶ Hence, penalties must be substantial enough to counter

⁶Grad, F. "A Treatise on Environmental Law," §2.03, pp. 2-166, 1973.

existing economic incentives, but should not be excessively high merely for the purposes of punishment.

Third, it was assumed that harmful quantities are best defined in terms of mass or volume of a material spilled rather than resulting concentration levels in receiving waters. Since substantial harm in the aquatic environment results from the presence of an excessive level of hazardous material, the determination of harmful quantity in these units requires the designation of both a critical volume of water, and a critical concentration of material defined as the threshold of harm. Each methodology offers a unique approach to selecting the former while a common rationale was employed to derive the latter. The details of these selection processes are presented in the following sections.

Finally, it was determined that while any single methodology is composed of distinct parts, each part should be designed as a discrete module that could stand alone or in combination with modules developed for other approaches. Therefore, while the results of the study are presented as four separate approaches, a much broader field of options is available to the regulatory agency through modular rearrangement of individual approach facets such as the base rate of penalty rationale, the adjustment mechanism for varying rates of penalty, and locational variables designed for post-spill penalty adjustment.

The text begins with a summary of the research effort. This is followed by a discussion of underlying concepts common to the development of approaches and then the discussion of each approach. Supporting work, input data on the physical-chemical and toxicological properties of designated non-removable hazardous substances,⁵ and harmful quantities and rates of penalty resulting from application of each methodology to these substances are appended in a separately bound volume.

REFERENCES

1. Thompson, C. H. and P. R. Heitzenrater. "The Environmental Protection Agency's Hazardous Material Spill Program," presented at the American Institute of Chemical Engineers Workshop, Charleston, WV, October 27-29, 1971.
2. Wilder, I. and J. Laforanara. "Control of Hazardous Material Spills in the Water Environment," Water and Sewage Works, 119: 1: 82, 1972.
3. Thompson, C. H. and K. E. Biglane. "Oil and Hazardous Materials--The Chemical Industry's Liability or Asset?", Chicago, IL, February 24, 1971.
4. Dawson, G. W., A. J. Shuckrow, and W. H. Swift. "Control of Spillage of Hazardous Polluting Substances," U.S. Environmental Protection Agency, FOZ 15090, October 1970.
5. Federal Register, Vol. 39, No. 164, Part IV, August 22, 1974.
6. Grad, F. "A Treatise on Environmental Law," §2.03, pp. 2-166, 1973.

II. SUMMARY

GENERAL

Section 311 of Public Law 92-500 requires among other things the formulation of regulations designating specific elements and compounds as hazardous substances and the subsequent delineation of harmful quantities for these substances. In addition, penalty rates are to be established for non-removable hazardous substances to motivate greater efforts in the area of spill prevention.

The objective of the subject study was to examine several of the technical alternatives available for developing harmful quantity and penalty rate regulations. A minimum of three distinct methodologies was to be developed for defining harmful quantities of designated hazardous substances and for establishing penalty rates.

For all methodologies, substances were characterized toxicologically on the basis of a critical concentration representative of the hazard posed by the substance when spilled into the aquatic environment. When possible, the selection of critical concentrations was based on 96 hour LC₅₀ data for bluegill and fathead minnows. This course of action was taken to ensure that potential harm resulting from release of harmful quantities would be substantial and that data input requirements would be tailored to available information. Using the critical concentration as a starting point, four individual methodologies were developed. Each has three identifiable segments: 1) a mechanism for deriving harmful quantities, 2) a rationale for the base rate of penalty, and 3) a scaling function to vary rates of penalty on the basis of the physical, chemical, and toxicological properties of individual materials. Additionally, two approaches offer locational variables which further refine penalty assessments based on the actual water uses and dispersive capacity of the receiving body. Each of these segments has been designed in modular fashion to allow the intermixing of preferred segments to form cohesive hybrid methodologies.

THE RESOURCE VALUE METHODOLOGY

The first approach focuses on the value of water resources potentially damaged by spills. A value of \$10,000 is employed as a threshold for defining substantial harm. Spilled quantities capable of producing damage in excess of that amount are defined as greater than harmful quantities. To quantify harmful quantities thus derived, various types of water bodies

are associated with per unit economic values based on those uses affected by spills. A harmful quantity is thereby set as the quantity capable of contaminating \$5,000 worth of environment to the critical concentration.

Rates of penalty are established which approximate the loss of the water resource. Therefore, initial rates are \$5,000 per harmful quantity. These rates are subsequently modified by coefficients formulated to reflect persistence and physical-chemical differences between materials which enhance or inhibit movement in the environment. Locational variables are also derived to account for resource values significantly different than the base averages employed and for the variable dispersive capacity of individual water bodies.

THE IMCO METHODOLOGY

The second approach illustrates the use of categorization by grouping hazardous materials into four basic hazard categories. This diminishes the number of calculations required in establishing harmful quantities and rates of penalty, and lends itself to coded labeling of shipment containers for more rapid recognition of hazard levels and regulatory requirements.

The categorization scheme itself is one developed by the joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) under the aegis of the Inter-Governmental Maritime Consultative Organization (IMCO).

Harmful quantities and rates of penalty are derived in the same manner as under the Resource Value Methodology; however, the critical concentration employed is that for the hazard group rather than for each individual material. Rates of penalty are adjusted with factors derived through a Delphi query intended to reflect the effect of a material's physical/chemical properties on its ability to exert its full hazard potential in the aquatic environment.

THE UNIT OF MEASUREMENT METHODOLOGY

The Unit of Measurement approach was designed to demonstrate use of a unit of measurement independently derived. The spectrum of liquid and dry shipping containers was reviewed and divided at the break between bulk containers and individual package units. The smallest bulk unit is defined as the harmful quantity for the least noxious hazardous materials as classified in the IMCO groupings. Harmful quantities for the remaining groups of materials are designated on the basis of their toxicities relative to the least hazardous

grouping and then rounded to the nearest actual container size.

Base rates of penalty are set at the statutory limit of \$1,000 per unit of measurement and modified downward through the use of the IMCO Methodology adjustment factors for individual materials.

THE DOHM METHODOLOGY

The DOHM approach focuses on the use of a plug flow model for derivation of harmful quantities. The model employs a statistically derived stream flow rate (95 percent of all U.S. stream waters flow in streams of this median flow rate or greater) to determine the quantity of a material required to produce a plug, contaminated to critical concentration which would take 96 hours to pass a stationary point. An application factor is derived modifying the model to apply to spills of short duration by compressing the plug. Similarly estuarine systems were characterized by their freshwater inflow. Harmful quantities for rivers were equated to those for lakes while harmful quantities for coastal waters were equated to those for estuaries.

Base rates of penalty are set equal to the cost of reasonable spill prevention measures and thus should provide the appropriate incentive for spill reduction. Rates established are based on industrial cost estimates and historical spill experience. Quantitative operators are developed to vary rates of penalty up to twice the base rate as a function of the dispersion potential, toxicity, and degradability of individual hazardous materials as required by Section 311. A means of modifying the plug flow model to determine site specific harmful quantities is also developed.

III. UNDERLYING CONCEPTS COMMON TO THE DEVELOPMENT OF ALL APPROACH METHODOLOGIES

GENERAL

Although the intent of the work reported herein has been the development of diverse methodologies for defining harmful quantities of hazardous materials and setting penalty rates, many underlying concepts are common to all the developed methodologies. Therefore, it is important to describe the overall framework within which methodologies were created before presenting detailed discussions on the technical development of each. In general, there are four broad areas which require review: 1) the practicality of implementation and enforcement of the methodologies; 2) the use of pure compound data and the subsequent need for adjustment when spills involve solutions or mixtures; 3) the manner of dealing with units of measurement; and 4) the selection criteria employed for assigning critical concentrations. Each of these considerations is discussed in detail in the subsequent sections of this chapter.

THE PRACTICALITY OF IMPLEMENTATION AND ENFORCEMENT OF THE METHODOLOGIES

Inherent in any regulatory mechanism is a tradeoff between the ease of implementing and enforcing the regulation and the degree of resolution that can be attained. That is, simplification of the self-reporting and penalty assessment aspects of a regulation necessarily results in a sacrifice in the degree of specificity afforded individual circumstances and incidences. Thus, an evaluation by the regulatory agency is required to balance the benefits and costs of the two extremes so that a near optimal blend of the two can be achieved. With respect to hazardous material spills, the most easily enforced approach would be the establishment of a single harmful quantity standard and a single rate of penalty. The approach with the greatest resolution would entail a complete post spill investigation of each incident with subsequent establishment of an equitable penalty.

Neither option is appropriate at the present time. The first would be inequitable in its treatment of discharges and would not comply with the law since it ignores the statutory requirement to consider "...such times, locations, circumstances, and conditions (which) will be harmful to the public health or welfare of the United States" [Section 311(b)(4)]. The second option is excessively burdensome in its demand for manpower, time, and finances and would not comply with the law since harmful quantities and rates of penalty must be developed a priori. It has been concluded by the authors that the best approaches

for setting harmful quantities and rates of penalty will be those which favor ease of implementation and workability on the part of both the regulating agency and those being regulated. For example, the extremely large number of potentially threatened waters in the United States have been condensed into four groupings based upon similar hydrodynamic characteristics: lakes, rivers, estuaries, and coastal zones.

USE OF PURE COMPOUNDS

Section 311(b)(2)(A) is very specific in its instruction to designate elements and compounds as hazardous substances. Additionally, most available data is pure compound oriented. This has led to the development of methodologies for defining harmful quantities and rates of penalty based on pure compound characteristics. It is recognized, however, that spills are not necessarily restricted to pure substances and all of the developed methodologies can be applied to mixtures; some more readily than others.

DESIGNATION OF UNITS OF MEASUREMENT

An integral part of the penalty structure outlined in Section 311 is the designation of a unit of measurement. Rates of penalty are then bounded in the range of \$100-\$1000 per unit of measurement. On the surface, this framework simplifies the task of selecting a unit of measurement common to each hazardous substance. However, for the vast majority of hazardous substances, there is no common unit of measurement. Materials are shipped in a variety of containers which span a wide range of sizes. Moreover, no sizes are standard with respect to stationary sources in that a plant operator may construct reactors, storage tanks, and other vessels of any desired size.

In the absence of an easily defined unit of measurement, it has been suggested that one can be derived at least for transportation spill sources by determining the average shipment size, or the average container size, based on annual shipping patterns. It is apparent, however, that a unit of measurement thus derived would be subject to yearly fluctuations as a result of changing market patterns. More important, however, is the fact that for most substances bulk shipments represent the vast majority of the total volume shipped. In many cases, the ability to ship in bulk and the size of bulk vessels is approved by Department of Transportation regulations and related exemptions. Changes in these policies could, therefore, abruptly alter the size and sometimes the order of magnitude of a statistically derived unit of measurement. Recent action concerning the bulk shipment of parathion serves as a prime example of such an abrupt change. Up until recently, guidelines restricted parathion shipments to small individually packaged units. The statistically derived unit

of measurement would have approximated a 208 liter (55 gallon) barrel. An exemption has been instituted, however, which now allows shipment in 45,420 liter (12,000 gallon) tank trucks. Though the material remained the same throughout the period of interest, the unit of measurement would have changed more than two orders of magnitude in response to a single regulatory policy shift. The rate of penalty would therefore drop in a commensurate manner on a per unit volume basis, and hence rates of penalty would become a function of transportation regulations which may not consider the environmental implications of hazardous substances. This would severely limit the ability of the law to scale penalties on the basis of the "...toxicity, degradability, and dispersal characteristics..." of a material.

Finally, the use of independently derived units of measurement inhibits any attempt to scale rates of penalty to levels with an economic significance, e.g., to exceed the cost of prevention and thus provide strong economic incentive to take steps to eliminate spills, or to repay society at a level commensurate with the value of the damaged resource. This leaves to chance the possibility that penalties will further the stated goals of Section 311 and in some way strike a balance between the costs to society of allowing spills to continue and those associated with strict prevention.

This last point is considered very important. Indeed, three of the four methodologies developed in this study attempt to define an appropriate level for penalties and thereby set units of measurement by a scaling procedure such that the penalties fall in the \$100-\$1000/unit of measurement range. In order to clarify the acceptability of such an approach within the framework of Section 311, an interpretation was sought from Mr. Leon Billings, Counsel for the Senate Committee on Public Works. His response¹ verified the validity of a dependent designation of units of measurement. Consequently, for the purpose of all but the Unit of Measurement Methodology, "units of measurement common to the trade" have been interpreted as any unit of measurement which one might employ in quoting prices or specifying quantities. Thus, units of measurement are multiples of common English units such as gallons, pounds, and tons.

For the most part, units of weight or mass were deemed the most appropriate for use. This is primarily due to the fact that mass units are common to all substances regardless of physical state, while volume units are arbitrary in dealing with solids. It is also common practice in the chemical industry to quote prices

¹Personal communication, Mr. Leon Billings, Counsel for the Senate Committee on Public Works, letter dated March 25, 1974.

on a per-unit-of-weight basis.² Only the Unit of Measurement Methodology differs from this standardization. This was instituted to reflect the fact that shipment containers for liquids are sized on a volume basis.

SELECTION CRITERIA FOR ESTABLISHING CRITICAL CONCENTRATIONS

There is no clear threshold such that spillage of more than a given amount of a contaminant constitutes harm at all locations and at all times while lesser amounts of the contaminant are totally harmless at all locations and at all times. Rather, the harm produced by the introduction of any pollutant to water is a continuous function dependent upon receiving water characteristics and measured in degrees of severity. Therefore, a key task in determining harmful quantities pursuant to the legal mandate of Section 311(b)(4) is the definition of when harm is severe enough to be considered substantial. This requires an evaluation of probabilistic damage or harm to representative water bodies, recognizing that the potential for variations in water quality and other factors to mitigate the effects of a spill limit the practicality of assessing damage a priori in any but relative terms.

Historically, the severity of harm resulting from the discharge of materials to water has been associated with the resulting concentration level of that material in the receiving body. For the purposes of the work reported here, the concentration where probable harm is considered substantial has been defined as the critical concentration. Naturally, this critical concentration varies with the chemical of interest and with the hazard type of concern. In order to establish critical concentrations for the development of the methodologies presented here, it was necessary for the authors to limit the hazard types and related concentrations that would be considered. Consequently, it was assumed that the best value to be employed was the 96 hr LC₅₀ for a median aquatic receptor. This assumption was based on the considerations presented in the following discussion.

The damage a substance can produce when present in water is closely associated with the uses of that segment of the water body and the effects the substances produces which may alter the water's value for that use. Therefore, damage can be separated into that associated with either withdrawal uses, or nonwithdrawal uses. Common uses in the first category include potable water supply, irrigation, and industrial water supply which may be damaged by substances characterized by oral toxicity to humans and livestock, taste and odor, phytotoxicity, corrosivity, and

²Oil Paint and Drug Reporter, September 1974.

flammability. Uses common to the second category including navigation, recreation, commercial and sport fishing, and aesthetics are threatened by substances which are characterized by toxicity to aquatic life; susceptibility to bioconcentration or the ability to taint fish flesh; toxicity via skin absorption; propensity to cause skin and eye irritation; exertion of biochemical oxygen demand; biostimulation; and odor, color, or other properties which lead to a reduction in amenities. The concentration levels at which these effects become significant are therefore the respective thresholds from which harmful quantities can be determined. While it is recognized that the final intended uses of water are all important, the thresholds associated with each may differ greatly for a single material, and hence one must be selected as the critical concentration upon which regulation will be based. That is, only a single framework can be employed for establishing a set of consistent standards. Factors bearing on the selection of a single framework include:

- The greater availability of data on levels of harm for nonwithdrawal uses vs that available for withdrawal uses (i.e., while aquatic toxicity data has been published for many substances, acute human toxicity and acute phytotoxicity information are not available. The limited data available on human and plant toxicity is directed to chronic exposure);
- The higher degree of protection afforded withdrawal uses as a result of various levels of pretreatment and water quality monitoring such as water treatment plants for municipal and industrial supplies;
- The fact that present civil law is better suited for recovery of damages to withdrawal use waters than to nonwithdrawal uses because of the greater ease of demonstrating damages (e.g., damage to crops from spills can be recovered directly by civil suit since the injured party is easily identified. Similarly, injuries resulting from consumption of poisoned municipal water can be settled in court.* Analyses to the aquatic environment are not so well protected against because of difficulties in quantification and identification of injured parties); and
- The added difficulty in assessing probable harm to withdrawal uses a priori as a result of additional probabilistic factors (e.g., location of intake, degree of pretreatment).

*A case in point is a settlement issued in Mississippi when a spill of sewage contaminated water withdrawn to raise minnows commercially. Judgement allowed recovery of income lost during the period of impact, \$30,000.¹

¹Records of Court Proceedings, State of Mississippi.

All of these points suggest the use of the nonwithdrawal framework for setting standards. Further, the authors recognize that harmful quantities are a self-reporting mechanism designed to aid in the reporting of spills which might otherwise go undetected. Spills impairing withdrawal uses are much more likely to be reported in the absence of such a mechanism than are spills impairing nonwithdrawal uses. For these reasons, the authors conclude that the major candidates for critical concentrations should be selected from the thresholds for substantial harm to nonwithdrawal uses.

It is further postulated that harmful quantities based on aquatic toxicity data will be lower than those derived from existing acute oral toxicity data for mammals. To verify this, a scenario must be developed to transform oral LD₅₀ values to acute aquatic concentrations. Existing drinking water limits are not appropriate, since they are designed to protect against chronic ingestion of toxins and do not reflect much higher exposures which can be safely endured over short time periods such as those associated with spill events. The scenario used here is based on a 70 Kg man consuming 2.5 liters of water a day. Thus, a material with a characteristic LD₅₀ of 5 mg/Kg body weight would be assigned a threshold concentration of

$$5 \text{ mg/Kg} \times 70 \text{ Kg} \div 2.5 \text{ liters} = 140 \text{ mg/l} \text{ (1.4 mg/l with a 100 fold safety factor applied)}$$

The relation is displayed graphically in Figure III-1 for a wide range of LD₅₀ values. Points on graph illustrate the relation between characteristic LD₅₀ and critical concentration based on fish toxicity data for representative substances. Clearly, for the vast majority (90 percent) of the randomly selected substances, the critical concentration selected as a result of aquatic toxicity is more restrictive than that for acute oral ingestion even after application of a 100 fold safety factor. For the four substances, the critical concentration derived from aquatic toxicity is more restrictive than that for acute oral ingestion with a 10 fold safety factor, but not a factor of 100. Consequently, the aquatic nonwithdrawal use framework is the more restrictive one within which to derive harmful quantities and rates of penalty. Data employed in this analysis can be found in Appendix A under the categories "Mammalian Toxicity" and "Freshwater Critical Concentration."

The effects which can impair nonwithdrawal uses differ greatly in significance and in the levels at which resulting harm is substantial. Color and odor may occur at low levels, but the reduction in amenities which may result is typically brief in duration and not easily defined as substantial harm in the context of nonwithdrawal use. Toxicity via skin absorption

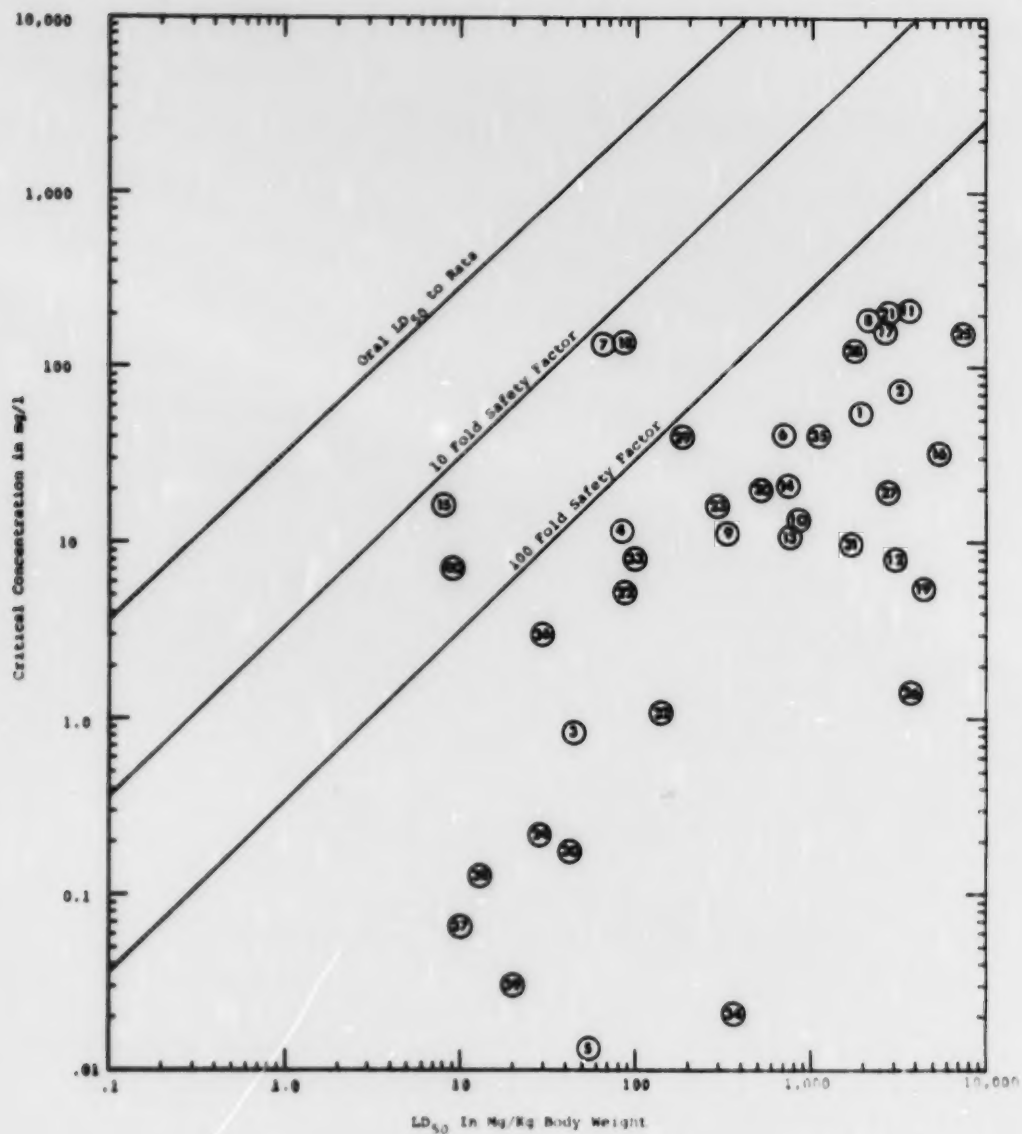


FIGURE III-1. RELATION BETWEEN LD₅₀ AND CRITICAL CONCENTRATION BASED ON HUMAN INGESTION

POINTS PLOT ORAL LD₅₀ VALUE FOR RAT VS CRITICAL
CONCENTRATION BASED ON AQUATIC TOXICITY

- | | |
|----------------------------|------------------------|
| 1. Acetaldehyde | 21. Butyric Acid |
| 2. Acetic Acid | 22. Cadmium Chloride |
| 3. Acrolein | 23. Calcium Arsenate |
| 4. Acrylonitrile | 24. Calcium Cyanide |
| 5. Aldrin | 25. Calcium Hydroxide |
| 6. Allyl Chloride | 26. Catechol |
| 7. Ammonium Bichromate | 27. Chlorobenzene |
| 8. Ammonium Formate | 28. Chloroform |
| 9. Ammonium Molybdate | 29. Cobaltous Chloride |
| 10. Ammonium Persulfate | 30. Coumaphos |
| 11. Ammonium Sulfamate | 31. Cresol |
| 12. Ammonium Sulfate | 32. Cupric Chloride |
| 13. Aniline | 33. 2,4-D Acid |
| 14. Antimony Pentachloride | 34. Diazinon |
| 15. Arsenic Pentoxide | 35. Dicamba |
| 16. Benzene | 36. Dinitrophenol |
| 17. Benzoic Acid | 37. Disulfoton |
| 18. Beryllium Chloride | 38. Ethion |
| 19. Butyl Acetate | 39. Guthion |
| 20. Butyl Amine | 40. Methyl Parathion |

and propensity to cause skin and eye irritation can lead to substantial harm; however, little quantitative data are available on the threshold levels at which these effects occur and, hence, critical concentrations cannot be identified for most substances. Further, these effects are usually the result of direct contact of neat solutions rather than contact with aqueous solution.

Bioconcentration is a hazard associated with a limited number of relatively persistent materials. Damage resulting from bioconcentration has been noted in only a few instances, and these were related to continuous discharges. Because it would require a heavy diet of aquatic life by a limited population in a restricted area over a prolonged period to initiate harm through bioaccumulation, the probability of this occurring as a result of an acute spill is quite low. At the same time, there are forces working to eliminate the materials from the affected organisms. Bioconcentration is reversible if given sufficient time.⁴ The use of critical concentrations derived from such an improbable event would at best be difficult to support and therefore such an approach has not been used. Rather, bioconcentrative properties are evaluated separately and used in adjusting rates of penalty to provide added incentive against spillage of these materials.

Exertion of biochemical oxygen demand (BOD) and biostimulation are also associated largely with chronic or continuous discharges but can conceivably result from acute spills. The critical BOD level will largely be a function of the site of the spill since dispersive characteristics, nutrients, normal dissolved oxygen levels, and the ability of a water body to reaerate are key factors in determining the development of DO related problems. Similarly, acute stress arising from the release of biostimulants will depend on the existing nutrient balance in the receiving water and other site specific variables. Any attempt to forecast harm for water bodies in general resulting from spills of materials posing these hazards would necessarily be excessively probabilistic in nature.

With respect to aquatic toxicity, data on the effects of various pollutant levels to aquatic life have been collected for a variety of substances and are reported in terms of the TL_m or LC_{50} . (The median tolerance limit, TL_m , is that concentration capable of inducing a given effect in 50 percent of the sample population in

⁴Battelle Memorial Institute. "Program for the Management of Hazardous Wastes," U. S. Environmental Protection Agency, Contract No. 68-01-0762, Vol. I, NTIS No. PB 233-630 and Vol. II, NTIS No. PB 233-631, July 1973.

the time specified. The LC₅₀ represents the median lethal concentration.) At the same time, fish kills and other signs of distress in the aquatic community have been the most frequently observed environmental impact noted for chemical spills.⁵ For these reasons, toxicity to aquatic life has been selected as the best hazard potential upon which to base critical concentrations. Selection of aquatic toxicity as the major property of interest is only a beginning. There are numerous parameters which must be characterized before a standardized threshold level is defined. Parameters of primary importance are type of effect, magnitude of effect, time span, and species. A discussion of the options available and the selection made for each parameter is given below.

Type of Effect

Stephan and Mount⁶ categorize potential hazardous effects on fish into three groupings:

1. Direct effects - effects involving direct toxic action on the receptor species.
2. Indirect effects - effects resulting from toxic action on other species which in turn have an effect on the species of concern, e.g., destruction of fish food organisms leaving the fish species of concern with a diminished food supply.
3. Induced effects - effects which occur as a result of the presence of a second toxic material which, when accompanied by the first, becomes a hazard at normal non-hazardous levels, e.g., synergism.

It is clear that direct toxic effects should be a major factor in selecting critical concentrations. There is a great deal of controversy, however, over similar use of indirect and induced effect thresholds. Induced effects, since they require the presence of a second toxic agent, are probabilistic in nature. It is difficult, if not impossible, to predict the occurrence of induced effects without focusing on a specific water at a given time when water quality parameters are well defined. In this respect, the use of induced effects would be similar to attempting to use BOD or biostimulation for developing critical concentrations. Consequently, induced effects should not be a primary concern.

⁵Dawson, G. W., A. J. Shuckrow and W. H. Swift. "Control of Spillage of Hazardous Polluting Substances," FWPCA, FO215090, October 1970.

⁶Stephan, C. E. and D. I. Mount. "Use of Toxicity Tests with Fish in Water Pollution Control," Biological Methods for the Assessment of Water Quality, ASTM, Philadelphia, PA, June 1973.

The question of use of indirect effects from acute spills is not so easily resolved for a number of reasons. Food fish organisms may represent a variety of trophic levels including algae, macrophytes, zooplankton, and macroinvertebrates. Individual species' sensitivities to toxic agents vary considerably such that any one species may be harmed at considerably lower concentrations than those at which direct effects occur. This then would suggest that the critical concentration should be the lowest concentration at which direct effects on any organism in the food chain occur. Clearly, this value will not be known for most substances. Indeed, in many areas the identity of the entire food web may not be established. Toxicity data for species other than fish are scattered, and certainly have not been generated systematically for the various food webs pertinent to important aquatic ecosystems. Testing is complicated by factors inherent in conducting bioassays and a lack of technique standardization. The task would be simplified if representative species were selected as indicator organisms. For instance, Daphnia magna are often studied as the standard freshwater macroinvertebrate. This simplification, however, works counter to the rationale for being concerned with indirect effects, since it is the weak link that determines the nature of the total resultant harm, and not the most commonly studied link. The Daphnia themselves may be the victims of indirect effects.

There is an even deeper problem than the latter, however, and that is the question of whether or not indirect effects will lead to substantial harm when they result from a discrete discharge. An acute change in species diversity may or may not be noticeable in the lower forms of aquatic life. Since hazardous material spills are relatively brief in duration, the arguments against changes in species diversity of any kind used in discussing continuous discharges may not be as valid. Organisms in lower trophic levels often have relatively rapid reproduction rates. Hence, the stress placed on the fish affected is often one of having to alter feeding patterns for a brief time only. In many ecosystems, alternative food sources may be available. Consequently, predicting substantial harm based on indirect effects to fish was not employed since it would have been highly probabilistic in much the same manner as the use of induced effects discussed earlier. Rather, the major source for critical concentrations employed in this study was toxicity data on direct effects to selected species of fish and shellfish with direct recreational and/or commercial value; or data indicating effects throughout an entire trophic level.

Similarly, lethality should be recognized as the toxic effect of interest as opposed to sublethal responses. The death of an important organism is clearly substantial harm, while sublethal effects arising from an acute discharge may or may not be substantial, depending upon their level and duration. Whereas

sublethal effects are of great concern in situations of continuous discharge, in acute spill situations it is much more difficult to assess their transient importance. Additionally, sublethal effects have been studied for only a few substances and standard testing procedures have not been developed. Data pertinent to setting critical concentrations on the basis of sublethal effects would be insufficient for most of the designated hazardous substances.

Magnitude of Effects

Having concluded that attention is best focused on direct lethality to fish or shellfish, it is necessary to specify the magnitude at which the effects become substantial. That is, the critical concentration is defined only after one specifies the percent of the affected population to which the substance is lethal. This specification is necessitated by the fact that individuals within a given species will differ in their ability to withstand toxic agents. Wuhrmann⁷ characterizes the variance in toxic response as one of normal distribution about a median response level. This means that the death of the first fish in a given population may not signal impending expiration for the remaining individuals. In fact, significant factors on the order of 2-3 have been reported between the concentrations where first and last death occurred in a fish population employed for toxicological research.⁸ While several points are generated during the bioassay analysis (10-100 percent mortality levels) only the 50 percent mortality level--LC₅₀--is typically reported in the literature. Indeed, the American Public Health Association notes in Standard Methods⁹ that the LC₅₀ is the standard measure of toxicity and must always be determined in bioassay work. Therefore, reliance on anything other than the median toxic limit would necessitate the use of data not frequently reported in the open literature and would lack the value carried by an accepted standard for measuring relative toxicity. Warren¹⁰ discusses the fact that natural populations typically oscillate as a result of interactive forces in the environment. It is uncertain that contamination to the LC₁₀ or LC₂₀ levels would produce fluctuations with any greater impact than these natural oscillations whereas there is little doubt in the mind of most

⁷Wuhrmann, K. "Concerning Some Principles of the Toxicology of Fish," Bull. Cent. Gelge Dacum. Eaux, No. 15, p. 49, 1952 (Fisheries Research Board of Canada Translation Series No. 243).

⁸Personal communication, Dr. Thomas Thatcher, Aquatic Biologist, Battelle-Northwest Laboratories, Richland, WA, 1974.

⁹Standard Methods for the Examination of Water and Wastewater, American Public Health Association, 12th ed., New York, 1969.

¹⁰Warren, C. E. Biology and Water Pollution Control, W. B. Saunders Company, Philadelphia, PA, 1971.

individuals that a 50 percent loss would be substantial. It is also important to note that laboratory bioassay results may not be directly proportional to effects in the field. The potential for variances in water quality and other factors to lessen the effects of a spill reemphasizes the fact that damage cannot be assessed in any but relative terms. Consequently, the best measure of potential damage is a widely acceptable relative index of toxicity such as the LC₅₀.

Duration of Effects

In addition to specifying the magnitude of effects, it is necessary to specify the time period over which the effects are exerted before a critical concentration can be selected. The concentration at which the LC₅₀ occurs varies with the time of exposure. In fact, time-dose mortality curves resemble equilateral hyperbolas when charted on arithmetical axes.¹¹ Consequently, comparative data for individual compounds must be associated with a set time of exposure before they have any meaning. Investigators commonly use 24, 48, and 96-hour periods in reporting bioassay results. The four-day, or 96-hour, period has been widely accepted as the most meaningful test duration when considering acute effects. Sprague¹¹ summarizes current research results with the statement that acute toxicity to fish generally occurs within the first 96-100 hours of exposure. The 96-hour LC₅₀ can then be considered as the lower end of acute effect concentrations. This becomes apparent from the time-dose mortality relations referred to above. For most substances, the 96-hour LC₅₀ concentration occurs after the shoulder of the curve and into the zone where the curve approaches the asymptote as illustrated in Figure III-2. This property has led to the use of 96 hour data to predict acceptable levels for chronic exposure through introduction of a numerical application factor ranging from 0.1 to 0.01.¹²

Application factors, however, are not considered appropriate for use here. Section 311(b)(4) states that

"The President shall by regulation, to be issued as soon as possible after the date of enactment of this paragraph, determine for the purposes of this section, those quantities of oil and any hazardous substance the discharge of which, at such times, locations, circumstances, and conditions, will be harmful to the public health or welfare of the United States..."

¹¹Burdick, G. E. "A Graphical Method for Deriving Threshold Values of Toxicity and the Equation of the Toxicity Curve," New York Fish and Game Journal, Vol. 4, No. 1, January 1957.

¹²Sprague, J. B. "Measurement of Pollutant Toxicity to Fish, I. Bioassay Methods for Acute Toxicity," Water Research, Vol. 3, 1969.

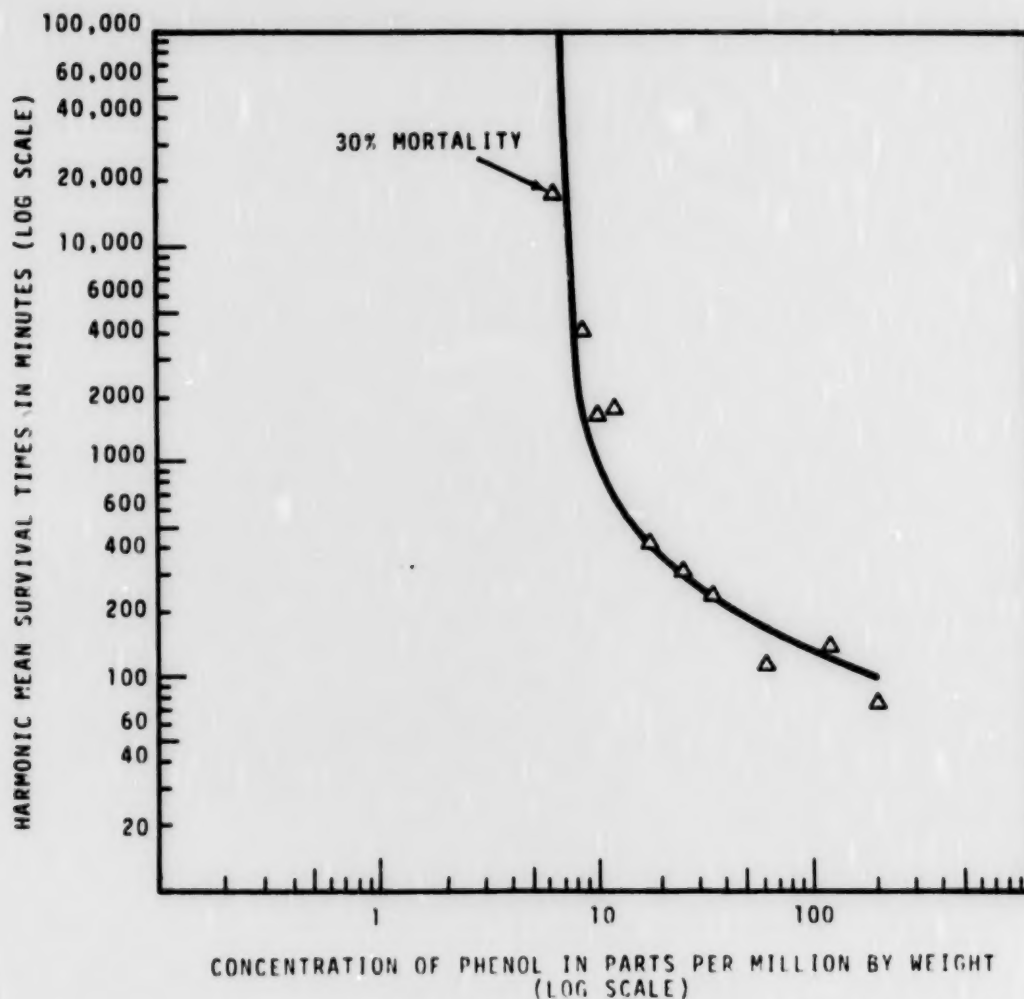


FIGURE III-2. SURVIVAL OF *R. heteromorpha* IN PHENOL SOLUTION (logarithmic time scale)³¹

³¹Abram, F. S. H. "An Application of Harmonics to Fish Toxicology," International J. Air/Water Pollution, Vol. 8, pp. 325-338, 1964.

Application factors, on the other hand, modify levels known to be harmful to "safe" levels.¹¹ Therefore, application factors are applied when chronic exposure is anticipated and water quality is to be maintained at a level safe to the exposed population. As noted earlier, spills are acute events and therefore should not be dealt with in the same manner as continuous discharges which pose a chronic threat. For a more detailed discussion of acute vs chronic effects and application factors, see Sprague.¹²

Acute toxicity, 96-hour LC₅₀, data appear very appropriate as a baseline for use in studying the effects of hazardous material spills. Spills are an acute phenomenon, and as such are well represented by acute toxicity relationships. Since 96 hours has been widely accepted as the threshold of acute exposure times, 96 hour bioassays are most appropriate for work directed to acute spills. Stephan and Mount⁶ note that acute mortality tests can indeed provide important information relative to the probable effects relative to spills of chemical compounds. Supporting data reflecting the distribution of spills by duration, however, are not presently available.

Although spill duration data are not available, fish kill duration data have been reported by the Department of the Interior and the U. S. Environmental Protection Agency and can be utilized as an estimate of the duration of fish exposure to the spill. Two assumptions have been made in considering the applicability of the data. The first is related to the spill source. It is not known what fraction of the reported kills represent kills due to non-spill related sources, e.g., runoff or leachate. Therefore, it must be assumed that the distribution pattern characteristic of all the reported kills is similar to that for kills resulting from acute spills. The second assumption bears on the relation between fish kill times and exposure times. It is assumed that there is a relationship between deaths and appearances of dead fish. Although the two time periods may be out of phase with respect to each other, it is assumed that the durations are essentially the same.

Figure III-3 graphically displays the data available for the duration of all pollution caused fish kills as reported in the period 1960-1970.¹³⁻²³ It can be observed from the plot that

¹¹Water Quality Criteria, National Academy of Sciences, EPA-R3-73-033, Environmental Protection Agency, (Advance Copy 1972).

¹⁴"Pollution-Caused Fish Kills in 1960," U. S. Department of Health, Education, and Welfare, Public Health Service, 1960.

¹⁵"Pollution-Caused Fish Kills January-September 1961," U. S. Department of Health, Education, and Welfare, Public Health Service, November 1961.

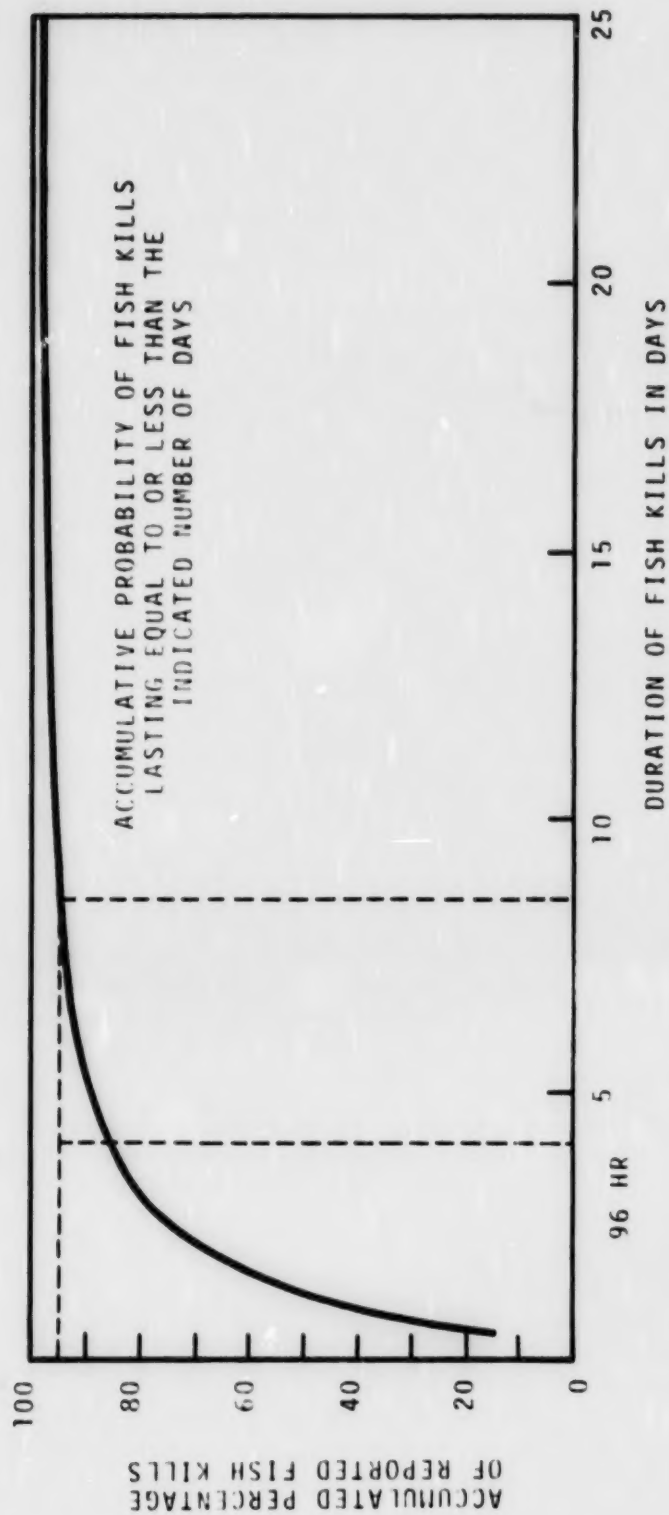


FIGURE III-3. ACCUMULATED PERCENTAGE OF REPORTED FISH KILLS VERSUS DURATION

95 percent of the kills were of a duration of nine days or less and that 85 percent of the fish kills had a duration of exposure equal to or less than 96 hours. As illustrated in Figure III-1, there is little difference expected between the 96-hour TL₅₀ and the 216-hour TL₅₀. Hence, the 96 hour exposure time can be considered as a relative measure of the longest period over which most acute spills will pose a substantial threat to aquatic life. This does not imply that all spills have a 96 hour duration. Rather, it contends that most will last 96 hours or less. Therefore, basing harmful quantities on an exposure period of 96 hours or less will be applicable to most spills. One must also distinguish between the time duration for emptying the vessel, and the time required for the spilled material to pass the receptor. It is the latter which is pertinent to the time span for which fish are exposed to a toxicant. The latter is typically greater than the former since the dispersive forces of the receiving water enlarge the contaminant plume with time. Hence, a spill that occurs over a four-hour period may extend to a longer duration plume as it travels downstream. As discussed above, the present fish kill data suggest that 96 hours is a reasonable upper boundary in most cases and it is to this time span that attention is directed.

In conclusion, the prevalence of 96-hour LC₅₀ data and the apparent significance of 96-hour toxicity levels with respect to fish kill plume time of passage indicate that the 96 hour LC₅₀ value for materials will constitute the most representative critical concentration. The test species, however, must still be designated to assure comparable analysis for determination of harmful quantity and rate of penalty for the various substances.

- ¹⁶"Pollution-Caused Fish Kills in 1963," U. S. Department of Health, Education, and Welfare, Public Health Service, 1963.
- ¹⁷"Pollution-Caused Fish Kills in 1964," U. S. Department of Health, Education, and Welfare, Public Health Service, 1964.
- ¹⁸"Pollution-Caused Fish Kills in 1965," U. S. Department of Health, Education, and Welfare, Public Health Service, 1965.
- ¹⁹"Fish Kills by Pollution in 1966," U. S. Department of the Interior, Federal Water Pollution Control Administration, Washington, DC, 1966.
- ²⁰"Pollution-Caused Fish Kills in 1967," U. S. Department of the Interior, Federal Water Pollution Control Administration, Washington, DC, 1967.
- ²¹"Pollution-Caused Fish Kills in 1968," U. S. Department of the Interior, Federal Water Pollution Control Administration, Washington, DC, 1968.
- ²²"1969 Fish Kills Caused by Pollution," Federal Water Quality Administration, USGPO, Washington, DC, 1970.
- ²³"Fish Kills Caused by Pollution in 1970," U. S. Environmental Protection Agency, USGPO, Washington, DC, 1972.

Receptor Species

The selection of a given species for a priority listing of preferred species is necessitated by the variance in sensitivity displayed among species of the same trophic level, genus, or family. Several investigators¹⁴⁻¹⁷ have found 3-4 fold differences in response between species when tested under identical conditions with the same toxicant. Other data suggest order of magnitude differences for some substances.²⁰ The relative order of sensitivity between species also differs with the substance tested. Wuhrmann¹ concludes that for each toxicant there is a particular order of sensitivity for fish species. Therefore, selection of a standard reference species can be a difficult task.

Doudoroff, et al.,²¹ suggest that due to their abundance and relative importance, freshwater species should be selected from the following families. Centrarchidae (sunfishes, basses, crappies); Salmonidae (trouts, chars, salmon); Cyprinidae (true minnows) excluding carp and goldfish; and Catostomidae (suckers). The obvious choice for any given situation would be the species common to the water body of interest. Unfortunately, there is no species common to all waters of the United States. Consequently, it was determined that a median sensitive species should be employed to be representative of the important species found in different environments throughout the country.

Work to date on water quality criteria¹² has focused on the most sensitive species as the receptor of concern, reflecting continuous discharge and chronic exposure circumstances. This is not appropriate for spill regulations since harmful quantities are associated with concentrations that "...will be harmful..." and the presence of the most sensitive species and the significance of that species in the affected waters are matters of conjecture. Use of a median receptor leads to concentrations likely to produce harm under median or most probable circumstances. The authors

¹⁴Thatcher, T. O. "The Comparative Lethal Toxicity of a Mixture of Hard ABS Detergent Products to Eleven Species of Fishes," Air and Water Pollution International Journal, Vol. 10, 1966.

¹⁵Pickering, Q. H. and C. Henderson. "The Acute Toxicity of Some Heavy Metals to Different Species of Warm Water Fishes," Proceedings of the 19th Industrial Waste Conference, Purdue University.

¹⁶Bunting, D. L., II. "The Relative Resistances of Seventeen Species of Fish to Petroleum Refinery Effluents and a Comparison of Some Possible Methods of Ranking Resistances," Thesis submitted at Oklahoma State University, August 1963.

¹⁷Katz, M. and G. G. Chadwick. "The Toxicity of an Endrin Formulation to Some Pacific Northwest Fishes," Robert A. Taft Sanitary Engineering Center, Public Health Service.

believe that this approach is better suited to the intent of the law. This does not imply that water quality can be allowed to slip to the levels associated with median receptor data. Rather, it implies that in a spill situation contamination can reach these levels before harm is likely.

With this in mind, bioassay data from McKee and Wolfe²⁸ were reviewed to establish a priority list of freshwater species. Input data for critical concentrations can then be selected giving preference to the high priority species. These rankings are presented in order of preference in Table III-1. On the basis of this review, Lepomis macrochirus (bluegill sunfish) was selected as the priority freshwater species. These members of the Centrarchidae family typically display a median level of sensitivity. They are widespread throughout the United States and are important both for their recreational fishing value and as a food source for larger, predatory sport fishes. Bluegills are easily kept and reared and therefore are commonly used in laboratory work. Consequently, bioassay data on this species are prevalent. Lower priority species were ranked according to their prevalence in the United States, and the availability of bioassay data. When only limited data were available, acute toxicity levels for other species were accepted. Selection of the order of preference following bluegill is illustrated in Figure III-4.

Fewer options are available when selecting critical concentrations for marine waters. Bioassay data on marine organisms are quite limited. Oysters and other economically important species are given top priority for marine waters. Abundance and importance in estuarine systems are the primary criteria here rather than sensitivity since a lack of data does not permit selection of a median sensitive receptor.

Other Considerations

It is known that critical concentrations may also change with other parameters such as temperature, pH, dissolved oxygen (DO), and general water quality conditions.²⁹ Therefore, an attempt has been made to select bioassay data obtained under similar conditions to ensure comparability. Selection is necessary because water quality varies considerably among water bodies in the United States and investigators often employ different test conditions to match those of interest, or do not report test conditions at all.

²⁸McKee, J. E. and H. W. Wolf. "Water Quality Criteria," U. S. Public Health Service/HEW, The Resources Agency of California, State Water Resources Control Board, Publication 3-A, April 1971.

²⁹Doudoroff, P., et al. "Bio-Assay Methods for the Evaluation of Acute Toxicity of Industrial Wastes to Fish," Sewage and Industrial Wastes, Vol. 23, No. 11, November 1951.

TABLE III-1

PRIORITY LISTING OF SPECIES FOR SELECTION
OF CRITICAL CONCENTRATIONS IN ORDER OF PREFERENCE

Freshwater Species

Lepomis macrochirus (Bluegill)
(Other Varieties of Sunfish)
Lepomis (Pumpkinseed, Orange spotted, etc.)
Pimephales promelas (Fathead minnow)
Micropterus (Bass)
Ictalurus (Catfish)
Gambusia affinis (Mosquitofish)
(Other Important Species)
Morone saxatilis (Striped bass)
Salmo or Salvelinus (Trout)
Gasterosteus aculeatus (Threespine stickleback)
Carassius auratus (Goldfish)
Lebistes reticulatus (Guppy)
Oncorhynchus (Salmon)

Saltwater Species

Crassostrea virginica or Ostrea spp (Oysters)
Mercenaria mercenaria or Mya spp (Clams)
Peneaus (Shrimp)
Callinectes or Carcinus (Crabs)
Fundulus (Killifish)
Cyprinodon variegatus (Sheepshead minnows)
(Other Important Species)
Morone saxatilis (Striped bass)

The effect of variations in test conditions differs with the substance of interest. For most industrial organic compounds potential differences can arise from variations in temperature, turbidity, and DO among other things. Wuhrmann⁶ reports an increase in median time to the LC₅₀ concentration of 20 to 50 minutes when DO changed from 4 to 8 ppm, respectively, for trout exposed to cresol. For inorganic materials such as cyanide and ammonia, pH and alkalinity can be especially important. Figure III-5 illustrates the change in the LC₅₀ value to trout for ammonia with variations in pH and alkalinity as summarized by Sprague.³⁰ With heavy metals, dissolved solids, hardness,

³⁰ Sprague, J. B. "Measurement of Pollutant Toxicity to Fish, II. Utilizing and Applying Bioassay Results," Water Research, Vol. 4, 1970.

organic chelates and complexants, and pH become extremely important because of the potential precipitation and subsequent removal from solution of the toxic agent. In studies with fathead minnows, Pickering and Henderson²³ found of water TL_m values for copper, cadmium, zinc and other metals from 50 to 100 times as great as those for hard water. Because the variations in water quality are site specific, a middle ground was necessary to indicate when the potential harm would be substantial for most natural waters. This was achieved by establishing a set of preferences whenever multiple data points were available for use. When data were available on species with similar sensitivity, highest priority was given to test results in waters similar to conditions existing in most natural waters. The pH range favored was 6.5-8.0 while hard water was given priority over soft water. In most cases, no other specifications were necessary since use of the 96-hour TL_m for bluegill or fathead minnows severely limited the number of alternative data points.

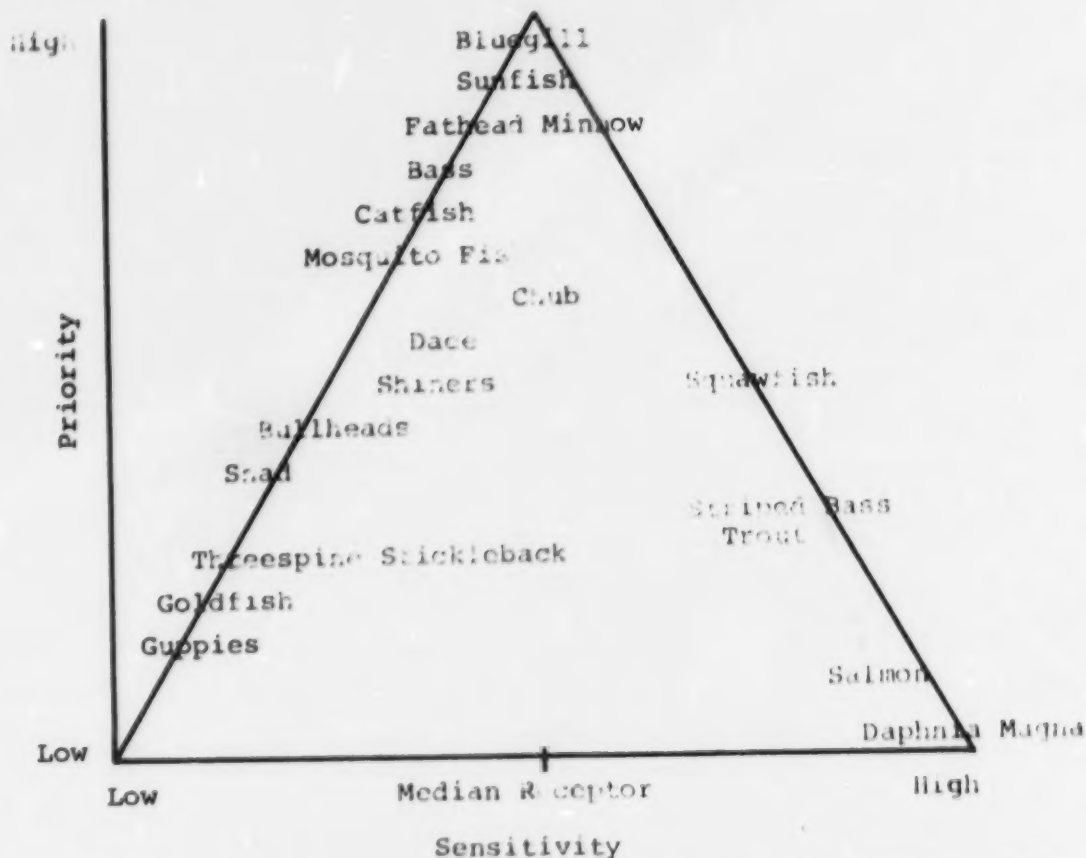


FIGURE III-4. SELECTION OF PRIORITY ORDER FOR RECEPTOR SPECIES

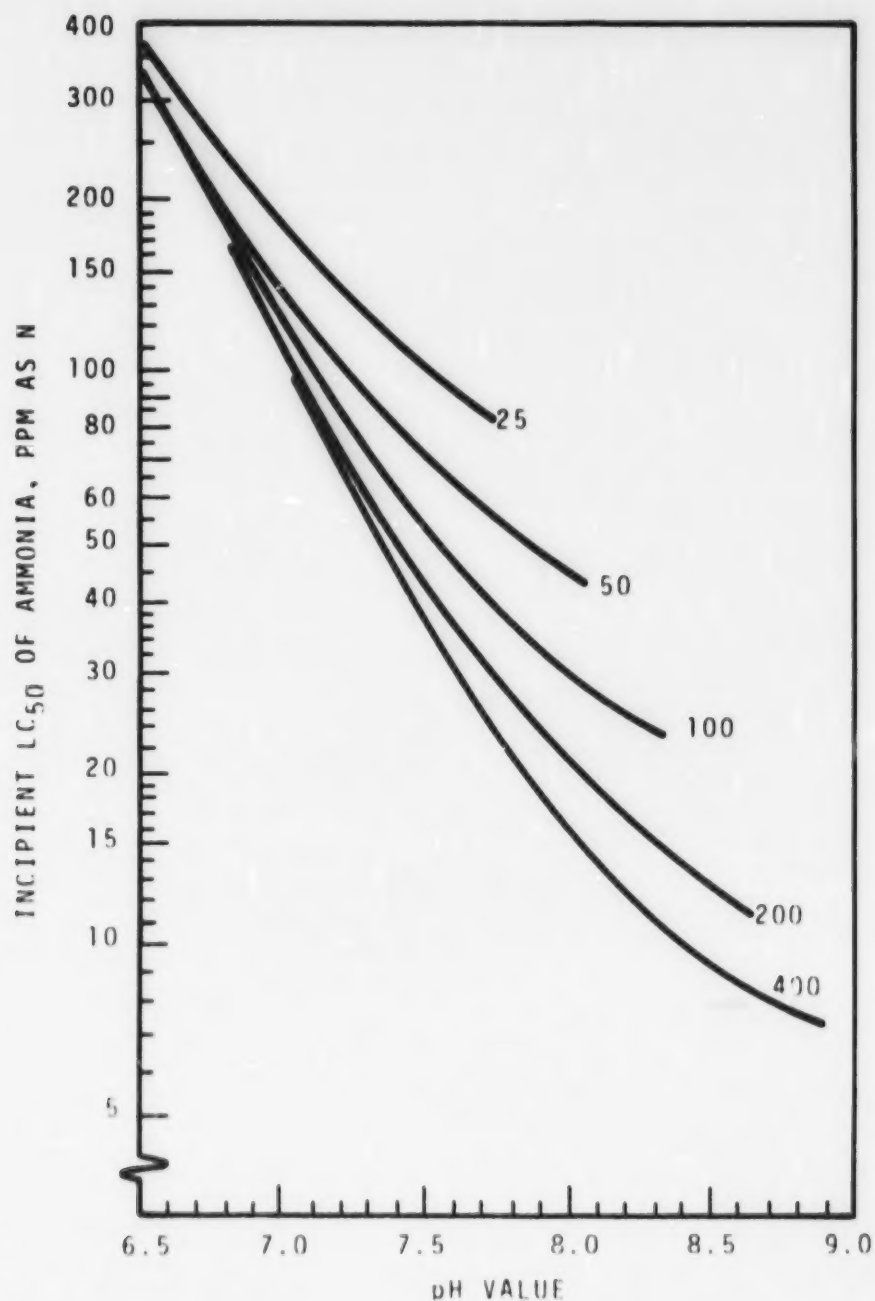


FIGURE III-5. THE VARIATION IN AMMONIA LC₅₀ VALUES WITH CHANGES IN pH AND ALKALINITY²⁵
(The numbers associated with each of the curves are alkalinity expressed as mg/l CaCO₃)

REFERENCES

1. Personal communication, Mr. Leon Billings, Counsel for the Senate Committee on Public Works, letter dated March 25, 1974.
2. Oil Paint and Drug Reporter, September 1974.
3. Records of Court Proceedings, State of Mississippi.
4. Battelle Memorial Institute. "Program for the Management of Hazardous Wastes," U. S. Environmental Protection Agency, Contract No. 68-01-0762, Vol. I, NTIS No. PB 233-630 and Vol. II, NTIS No. PB 233-631, July 1973.
5. Dawson, G. W., A. J. Shuckrow and W. H. Swift. "Control of Spillage of Hazardous Polluting Substances," FWPCA, FO215090, October 1970.
6. Stephan, C. E. and D. I. Mount. "Use of Toxicity Tests with Fish in Water Pollution Control," Biological Methods for the Assessment of Water Quality, ASTM, Philadelphia, PA, June 1973.
7. Wuhrmann, K. "Concerning Some Principles of the Toxicology of Fish," Bull. Cent. Gelge Dacum. Eaux, No. 15, p. 49, 1952 (Fisheries Research Board of Canada Translation Series No. 243).
8. Personal communication, Dr. Thomas Thatcher, Aquatic Biologist, Battelle-Northwest Laboratories, 1974.
9. Standard Methods for the Examination of Water and Wastewater, American Public Health Association, 12th ed., New York, 1969.
10. Warren, C. E. Biology and Water Pollution Control, W. B. Saunders Company, Philadelphia, PA, 1971.
11. Burdick, G. E. "A Graphical Method for Deriving Threshold Values of Toxicity and the Equation of the Toxicity Curve," New York Fish and Game Journal, Vol. 4, No. 1, January 1957.
12. Sprague, J. B. "Measurement of Pollutant Toxicity to Fish, I. Bioassay Methods for Acute Toxicity," Water Research, Vol. 3, 1969.
13. Water Quality Criteria, National Academy of Sciences, EPA-R3-73-033, Environmental Protection Agency, (Advance Copy 1972).

14. "Pollution-Caused Fish Kills in 1960," U. S. Department of Health, Education, and Welfare, Public Health Service, Washington, DC, 1960.
15. "Pollution-Caused Fish Kills January-September 1961," U. S. Department of Health, Education, and Welfare, Public Health Service, Washington, DC, November 1961.
16. "Pollution-Caused Fish Kills in 1963," U. S. Department of Health, Education, and Welfare, Public Health Service, Washington, DC, 1963.
17. "Pollution-Caused Fish Kills in 1964," U. S. Department of Health, Education, and Welfare, Public Health Service, Washington, DC, 1964.
18. "Pollution-Caused Fish Kills in 1965," U. S. Department of the Interior, Federal Water Pollution Control Administration, Washington, DC, 1965.
19. "Fish Kills by Pollution in 1966," U. S. Department of the Interior, Federal Water Pollution Control Administration, Washington, DC, 1966.
20. "Pollution-Caused Fish Kills in 1967," U. S. Department of the Interior, Federal Water Pollution Control Administration, Washington, DC, 1967.
21. "Pollution-Caused Fish Kills in 1968," U. S. Department of the Interior, Federal Water Pollution Control Administration Washington, DC, 1968.
22. "1969 Fish Kills Caused by Pollution," Federal Water Quality Administration, USGPO, Washington, DC, 1970.
23. "Fish Kills Caused by Pollution in 1970," U. S. Environmental Protection Agency, USGPO, Washington, DC, 1972.
24. Thatcher, T. O. "The Comparative Lethal Toxicity of a Mixture of Hard ABS Detergent Products to Eleven Species of Fishes," Air and Water Pollution International Journal, Vol. 10, 1966.
25. Thatcher, Q. H. and C. Henderson. "The Acute Toxicity of Some Heavy Metals to Different Species of Warm Water Fishes," Proceedings of the 19th Industrial Waste Conference, Purdue University.
26. Bunting, D. L., II. "The Relative Resistances of Seventeen Species of Fish to Petroleum Refinery Effluents and a Comparison of Some Possible Methods of Ranking Resistances," Thesis submitted at Oklahoma State University, August 1963.

27. Katz, M. and G. G. Chadwick. "The Toxicity of an Endrin Formulation to Some Pacific Northwest Fishes," Robert A. Taft Sanitary Engineering Center, Public Health Service.
28. McKee, J. E. and H. W. Wolf. "Water Quality Criteria," U. S. Public Health Service/HEW, The Resource Agency of California, State Water Resources Control Board, Publication 3-A, April 1971.
29. Doudoroff, P., et al. "Bio-Assay Methods for the Evaluation of Acute Toxicity of Industrial Wastes to Fish," Sewage and Industrial Wastes, Vol. 23, No. 11, November 1951.
30. Sprague, J. B. "Measurement of Pollutant Toxicity to Fish, II. Utilizing and Applying Bioassay Results," Water Research, Vol. 4, 1970.
31. Abram, F. S. H. "An Application of Harmonics to Fish Toxicology," International J. Air/Water Pollution, Vol. 8, pp. 325-338, 1964.

IV. THE RESOURCE VALUE METHODOLOGY

BRIEF

The methodology developed in the following discussion directs attention to the economic value of environmental resources and their potential loss as a result of the spillage of hazardous materials. Harm is defined as a threshold dollar value such that damage in excess of that amount is considered substantial. The threshold itself is selected through a decision analysis process with the intent of keeping the threshold in a reasonable range without encouraging the discharger to gamble by failing to report spills of quantities equal to or greater than the harmful quantity.

Rates of penalty are derived to be commensurate with the value of resources damaged. This provides for the internalization of the costs to society of individual spills. Whereas past spill site-specific damage assessment studies generally are deemed unnecessarily expensive, adjustment factors are developed which may be used to modify penalties on the basis of key environmental parameters in the area of the spill. The information flow required for the Resource Value Methodology is illustrated in Figure IV-1.

VALUE THRESHOLD

The Resource Value Methodology approach was designed to directly define a threshold at which harm becomes substantial. Implicit in the selection of a harmful quantity is the assumption that some given amount of damage can be viewed as too small to warrant reporting to, and followup action by, the federal government. This implies that there is some amount of harm that society is willing to accept. Potential harm in excess of that amount is substantial and therefore should be reported.

Two alternative methods for selecting the dividing line between acceptable and substantial harm were examined in this work: 1) designation of some minimum volume of water for which potential contamination is deemed significant, and 2) selection of a damage value level which, if exceeded, defines substantial harm. The former approach proved to be fruitless.

Neither legal precedence nor practical divisions, such as those employed for stocking fish and game, were found to provide sufficient uniformity to be of use. For instance, the Bureau of Sports Fisheries and Wildlife, Department of the Interior, typically will not plant lakes of a size less than 202 surface hectares (500 surface acres). Similarly, the Environmental

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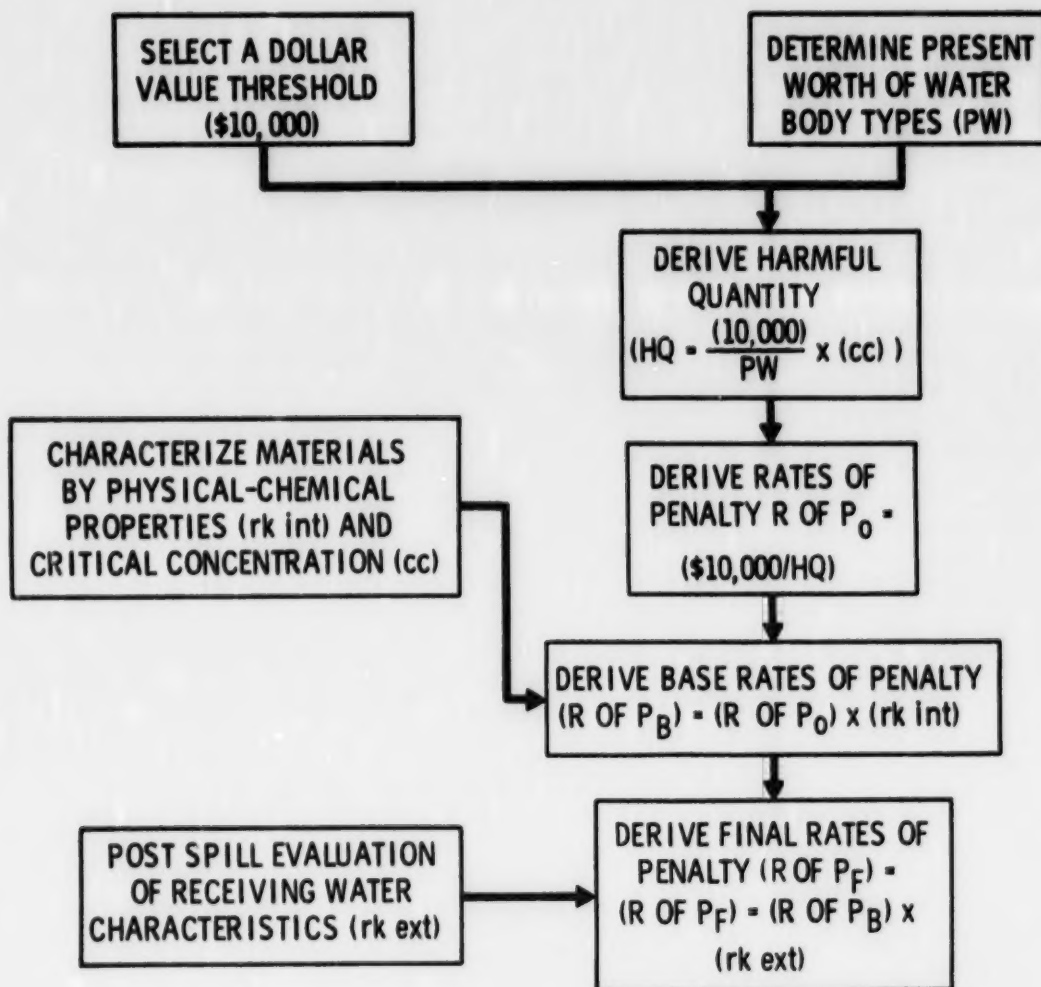


FIGURE IV-1. FLOW DIAGRAM FOR RESOURCE VALUE METHODOLOGY

Protection Agency lake rehabilitation program will not direct efforts to lakes with less than 40 surface hectares (100 surface acres).¹ Some state agencies, on the other hand, maintain that they will plant any body of water with recreation potential regardless of size. Hence, the water body size becomes a function of the species to be planted and the location where planting is anticipated.

Due to the lack of uniformity among practices and the absence of definition of some critical volume of water in legal precedence, this approach was deemed unsatisfactory. The selection of any single threshold would be arbitrary and, hence, subject to a great deal of criticism. Economic thresholds, however, were found to hold greater promise.

The economic threshold approach strives to establish a damage value level which, when exceeded, represents a significant enough potential loss to society that reporting and subsequent federal action are warranted. There is precedence for such an approach in previous regulations. Section 20.403 of Title 10 of the Code of Federal Regulations calls for notification of incidents involving radioactive materials when damage to property is in excess of \$1000. Similarly, the Department of Transportation requires reporting on all incidents involving hazardous materials where property damage exceeds \$50,000. Section 311 of the Federal Water Pollution Control Act Amendments of 1972 includes several economic values which appear to be considered significant in the eyes of Congress. Monetary amounts specified in Section 311 range from \$500 to \$5,000,000. Congress has set \$10,000 (and a one year jail sentence) as the maximum criminal penalty for failure to report a spill of a hazardous substance in excess of the harmful quantity. If the rate of penalty for spillage is to be based on the value of potential damage to the environment and the harmful quantity is selected from a maximum acceptable damage level, then reporting a spill of exactly a harmful quantity will automatically entail a fine equivalent to the threshold selected and up to an additional \$5000 for spilling an amount in excess of the harmful quantity [Section 311(b)(6)]. This suggests that the threshold should not exceed \$10,000. The reason for this is that at the margin (i.e., when just a harmful quantity is spilled) the responsible agent will weigh the merits of reporting the spill and not reporting based on the penalties involved. If reporting will obligate a spiller to a fine in excess of \$10,000, he may be willing to take the risk of not reporting, thus becoming liable for both the civil penalty and the \$10,000 criminal penalty. The non-removable penalty will always be assessed. The

¹Personal communication, Thomas Maloney, EPA/NERC, Corvallis, OR, February 13, 1974.

\$5,000 harmful quantity penalty, however, can vary from 0 up to \$5000 and thus may not be assessed at all. On the other hand, if the fine is less than or equal to \$10,000, he is more likely to report the spill and thus bring about the desired result. Setting the damage threshold no higher than \$10,000 should achieve the latter result since the difference between a criminal and a civil penalty and the possibility of imprisonment favor reporting the spill.

When spills significantly exceed the harmful quantity, the likelihood of their going unnoticed diminishes rapidly, and the responsible agent is clearly motivated to report. Thus, setting the damage threshold level no higher than \$10,000 should provide adequate incentive for reporting all spills of harmful quantities or more. The tradeoff analysis described above is presented in a decision tree form in Figure IV-2. Assuming no harmful quantity penalty is assessed, reporting would cost the spiller \$10,000, while failure to report would have an average cost of $\$20,000 \times (m)$ in the long run, where m is the probability of the spill being detected. Clearly, if m is 0.5 or greater, a report should be filed. The additional threat of imprisonment reduces the level of m necessary for reaching the equi-cost point. Assuming the maximum harmful quantity spill penalty of \$5000 is also assessed, the equi-cost probability, m , rises to 0.6. Therefore, the potential of an additional \$0-\$5000 penalty for reporting the spill varies the equi-cost probability from 0.5 to 0.6 if the \$10,000 threshold is not exceeded. Since harmful quantities are to be selected such that a high probability of damage exists, it is reasonable to expect that m will exceed this equi-cost range (0.5-0.6). That is, spillage of a harmful quantity should cause sufficient harm to be readily observed, and third party detection is likely to occur.

As the quantity spilled increases, m rapidly approaches one. At the same time, the cost of not reporting and being caught always exceeds the cost of reporting by \$10,000. Hence, reporting should continue to be the alternative of least cost.

It is clear that without a quantitative estimate of the probability m , the optimal level for the threshold cannot be selected. The use of \$10,000, however, appears to be sufficient to gain the desired end. At the same time, there is reason to believe that \$10,000 should be considered as substantial, since Congress has selected that level as the maximum for criminal penalties which, by definition, are established to punish undesirable activity.²

Therefore, the threshold should not exceed \$10,000. It could, however, be set lower. Congress has suggested in Section 311(b)(2)(B)(iii)(aa) that amounts as little as \$500-\$5000 may be adequate

²Grad, F. A Treatise on Environmental Law, §2.03, 2-166, 1973.

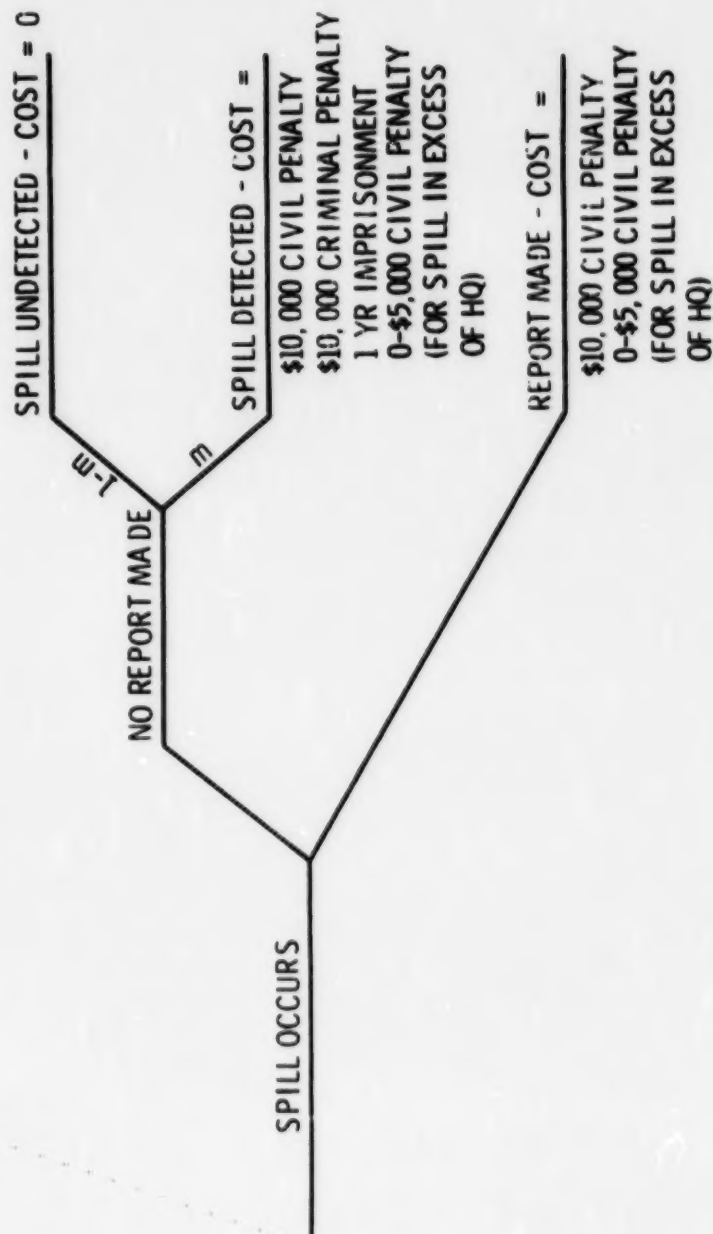


FIGURE IV-2. DECISION TREE FACING AGENT WHEN HARMFUL QUANTITY IS SPILLED AND THRESHOLD IS SET AT \$10,000

penalties on a per spill basis. The U. S. Coast Guard has also been given the authority to assign penalties of up to \$5000 on a per spill basis. Consequently, one can assume that these levels would be considered substantial within the context of the law. These levels are low, however, when compared to potential costs for responding to reports and enacting enforcement. Indeed, response costs are likely to exceed the \$2,000 per spill estimated expenditures for enforcing the present oil spill regulations.³ It would seem irrational to report spills with damage levels below the cost of processing the report itself. Therefore, \$2,000-\$10,000 appears to be the most reasonable range for a threshold value within the present framework.

The harmful quantity penalty (up to \$5000) directed by the Coast Guard, can play an important role here. If the value threshold is set at the same \$5000 level, then a spill of a harmful quantity will lead to an option baserate of penalty of \$5,000. This would equal the maximum penalty for a spill of a harmful quantity prescribed by Congress. Subsequent adjustment factors would scale this down, but in essence, Congressional intent would be met, in that the penalty for a spill of a harmful quantity would not exceed \$5000. Further, since \$2000 may be a low estimate of the cost of responding to spills, this penalty level would be likely to represent values in excess of costs for response. Finally, \$5,000 falls between the desired \$2000 to \$10,000 range and therefore satisfies all considerations. For the above reasons, \$5,000 has been selected as the dollar threshold distinguishing the point at which potential damage becomes substantial.

SELECTION OF THE CRITICAL VOLUME FOR LAKES

The selection of an economic damage level threshold in the range required to provide incentive for reporting still requires the association of dollar values with quantities of water (i.e., cubic meters of lake water), so that a critical volume can be associated with the \$5000 level. This is necessary since substantial harm is defined in terms of concentration and harmful quantities are to specified in units of mass. Once a critical volume has been established, one can convert between the two sets of units. In order to provide such an association, data were collected on the size and value of various water bodies throughout the country. Valuation processes included bond levels approved for restoring lakes, industrial development, income foregone to preserve aesthetic qualities, purchase price, and the present worth of annual recreation and commercial based income. It is apparent, from the data, that a given volume of natural water is subject to varying marginal costs or values as are

³Personal communication, Dr. A. L. Jennings, EPA/Division of Oil and Hazardous Materials, Washington, DC, July 24, 1974.

most economic goods; that is, as a lake becomes larger, the incremental value of an additional unit volume of water becomes smaller.

When the freshwater data were plotted on a scatter diagram, the points demonstrated too great a spread to form a single relation. Consequently, the individual points were segregated according to the valuation method employed to obtain them. It is clear that most valuation procedures establish a relatively smooth relation illustrating diminishing marginal values with increasing size. The curves also form an envelope indicating a range of values as a function of the specific valuation procedures. These procedures in turn can be correlated with specific water uses and values, some of which will not necessarily be affected by a spill. Therefore, one must select the valuation method which reflects uses directly impaired by spills and employ that method as the basis of assessing environmental harm.

Five basic valuation methods were employed in constructing Figure IV-3.

1. Cost of Constructing and Operating Treatment Facilities to Maintain or Improve Quality in the Receiving Water - These values should be considered as minimum ones since it is implied that the water quality is worth at least that much to society or the facilities would not have been built.
2. The Recreational Benefits Derived from the Water Body - These values are typically derived on a user-day basis with dollar values established for the average recreation day. Most values include sport fishing, boating, and swimming activities.
3. The Purchase Price - These values represent the sale of the lake in question. These may be overvalued since land is included in the purchase to varying degrees and cannot be separated out on a fractional cost basis.
4. The Cost of Constructing and Maintaining an Artificial Lake - These values relate the experience of state agencies and private developers in creating new lakes.
5. The Value Foregone with Loss of the Lake - This methodology includes values billed as the "total social" worth of a lake and the use values attributed to lakes with exceptionally high use rates, such as small water bodies in highly urbanized areas.

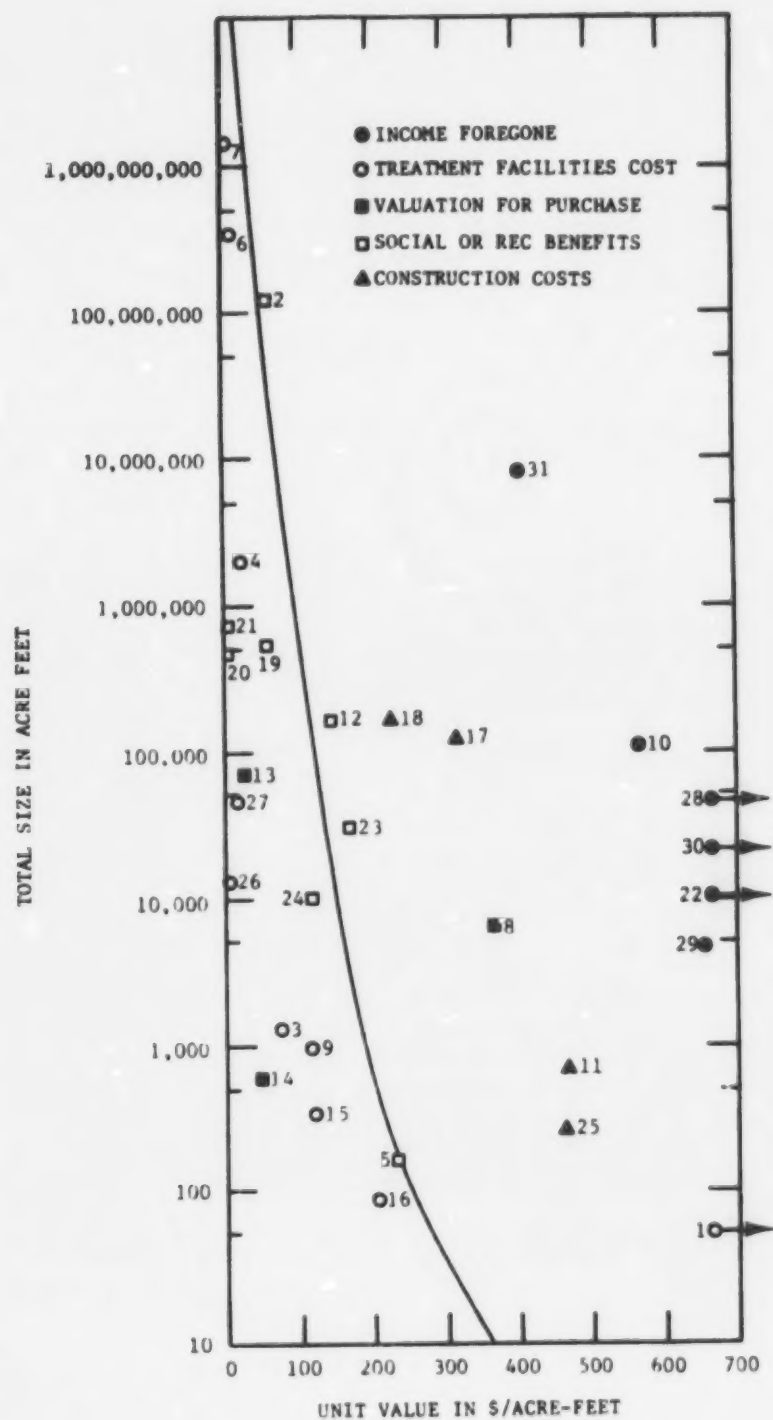


FIGURE IV-3. UNIT VALUES FOR A GIVEN VOLUME OF LAKE WATER AS A FUNCTION OF OVERALL LAKE SIZE (NUMBERS ARE KEYED TO DESCRIPTIVE MATERIAL CONCERNING VALUATION METHOD AND REFERENCES WHICH ARE GIVEN IN APPENDIX B)

Specific derivations for each of the points in Figure IV-3 are listed in the notes contained in Appendix B.

Of the evaluation methods employed, only the second deals with uses directly affected by hazardous material spills (i.e., sports fishing and water contact recreation). The first method merely sets a minimum value level while the third method includes additional land and other considerations which cannot be segregated. The fourth and fifth methods also include other use considerations such as property value considerations, aesthetics, and flood control which will not be totally lost as a result of a spill. The best fit relation illustrated is that for the second valuation method, recreational benefits, which is defined as the pertinent value system for this analysis. It is readily apparent that the pertinent marginal values vary with the size of the lake. The weighted average present worth was found to be \$63.47/acre-foot or \$3.20/acre-foot/year. (weighting was based on volume.)

This compares quite favorably with the \$3-5/acre-foot/year by the National Water Commission⁴ for recreational waters. It is low, however, when compared with estimates by the Council on Environmental Quality as to the expenditures required to meet present water quality goals for 1982 (\$18.2 billion/year)⁵ as allocated to average annual runoff (2×10^9 acre-feet/year):⁶ \$9/acre-foot/year. It is also low compared to values developed by the U. S. Water Resources Council and the U. S. Fish and Wildlife Service for recreational expenditures for sport fishing. These and other values are compared and evaluated in Table IV-1. Considering the comments in Table IV-1, it would appear that the \$9 figure of expenditures required is a maximum value. That is, allocations and actual compliance with 1982 goals may fall short of the required amounts. At the same time, the relative size of this value and the admitted conservative nature of the Colorado State University work suggests that the high end of the \$3-5/acre-foot/year range is most appropriate. With this in mind, \$5/acre-foot/year has been selected as the value of lake waters. This corresponds with an annual value of \$0.0042 per cubic meter and a present worth of \$0.067 per cubic meter (\$83 per acre-foot). Therefore, for the purposes of this methodology, the critical volume for lakes has been selected as 74,277 cubic meters (60.24 acre-feet).

⁴"Water Policies for the Future," final report to Congress of the National Water Commission, USGPO, June 1973.

⁵"Environmental Quality - 1974," Fifth Annual Report of the Council on Environmental Quality, Washington, DC, USGPO, December 1974.

⁶Todd, D. K. The Water Encyclopedia, the Maple Press Company for the Water Information Center, 1970.

TABLE IV-1

VALUATION OF FRESHWATERS IN U. S. BY VARIOUS SOURCES

Value (\$/Acre Feet/yr)	Method Employed	Comments
\$3-\$5	Colorado State University & National Water Commission Estimates	Conservative Valuation Method Employed
\$.38	Average of Recreational Values Derived by Authors	Limited Data on Lakes only - Some Admittedly Undervalued
\$2-\$4/acre-feet	Cost of Rehabilitating Fish Lakes in Oregon	Duration of Effectiveness is Variable
\$1.50-\$29/acre- feet	Cost of Rehabilitating Fish Lakes in New York	Duration of Effectiveness is Variable
\$2-\$12	Cost of Constructing Recre- ational Lakes in Colorado	Highly Dependent on Local Variables
\$9	Cost of Meeting 1982 Stand- ards allocated to Annual Runoff	Assumes most cleanup will Effect Rivers
\$12	Expenditures for Sport Fishing	Assumes three Spent Per Recreation Day and only Values Waters used for Fishing

SELECTION OF A CRITICAL VOLUME FOR ESTUARIES

Estuarine values were collected on the basis of revenues for sport and commercial catches. In this case, the values were found to be more closely grouped. In turn, estuarine values were found to have little scatter when total present worth was plotted against total acreage, as in Figure IV-4. The typical evaluation method involved determination of the dollar value of annual commercial and sport fishing activities. The individual quantities employed are given in the notes in Appendix B. Little change in marginal values was found with increased size. This is reasonable since the average productivity does not change directly with size. The value for the nation, however, is larger, \$1273/acre, than the average for the ten estuaries studies, \$712/acre. Both values are much lower than the value of \$4280/acre derived by sport fishing interests.⁷

This latter figure is high because only the productive estuarine systems were considered. Given these considerations, the national average, value No. 1 in Figure IV-4 was selected as the pertinent value. If an average depth of 3.0 meters (10 feet) is assumed, this corresponds to a present worth of \$0.1016 per cubic meters (\$127/acre-feet) and a critical volume of 49,212 cubic meters (39 acre-feet).

⁷Sullivan, C. R. "Economic and Social Significances of Sport Fishing," National Conference on Complete Water Reuse, AICHE-EPA Technology Transfer Series, April 23-27, 1973.

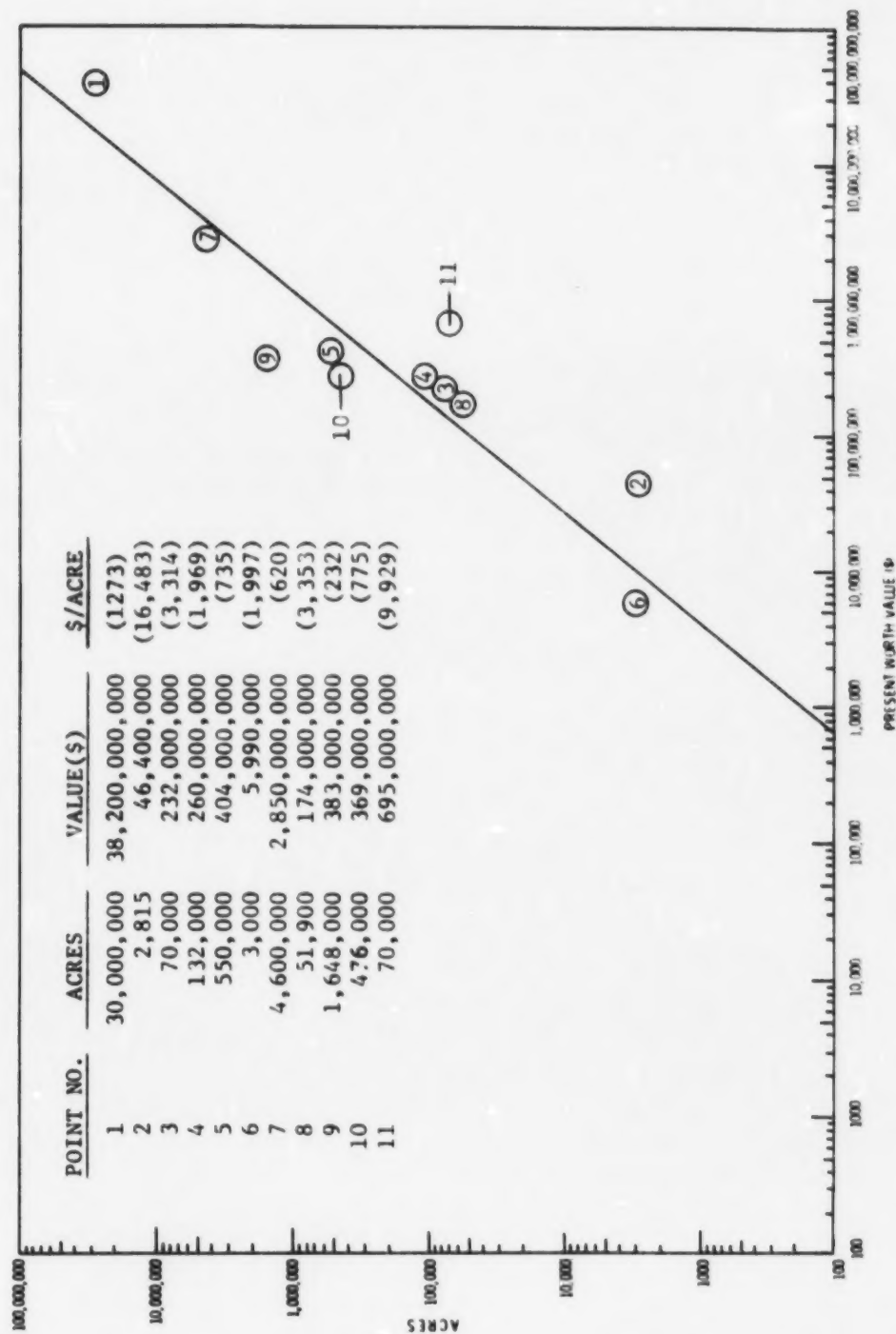


FIGURE IV-4. PRESENT WORTH OF ESTUARINE SYSTEMS AS A FUNCTION OF THEIR SIZE

SELECTION OF A CRITICAL VOLUME FOR RIVERS

An attempt was made to value rivers in much the same manner that lakes were valued. It quickly became evident, however, that there were problems inherent in this approach which could not be reconciled. A major stumbling block was the method of valuation. The few attempts that have been made to value rivers have focused on river frontage or run length as the basic unit rather than volume of water. Without a volume specified, no means exists to transform critical concentrations into harmful quantities. Secondly, it was found that the few valuations that have been made are insufficient to formulate any relations which can be applied to rivers as a whole.

With these limitations in mind, it is apparent that, for the present, river water must be valued on a volume basis through correlation to the lake values obtained. This concession is more soundly based than might appear in that many lakes are indeed reservoirs on rivers, and the interchange between lakes and rivers in terms of sources and outlets is often very important.

There are two considerations with major impact on the value of river waters versus the value of lake water. The first relates to the fact that a single plug of contaminated river water may move downstream and, consequently, may threaten an aquatic community much larger than would normally reside in that volume of water alone. For instance, a plug of toxicant will not only kill fish in that volume of water but may also kill other fish which it passes in the river until it is diluted below the critical concentration. This consideration suggests then that river water must be valued higher than lake water because a given plug can produce more damage.

The second consideration concerns the dispersion aspects and regenerative capacity of the river. The flowing river inherently is associated with far greater forces of mixing than impounded water and thus can dilute a spill to nontoxic levels much more rapidly than lake water which relies heavily on diffusion dynamics. At the same time, the river is constantly replenishing itself with water and life forms from upstream. These characteristics would suggest that greater amounts of materials could be assimilated without substantial harm and, hence, harmful quantities should be larger and rates of penalties smaller than those for discharges to lakes.

There is no rigorous manner in which these two forces can be quantitatively evaluated. Consequently, the harmful quantities derived for lakes were also applied to rivers. Implicit in this interchange of values is the assumption that it is the

volume of water potentially damaged which is being valued, and that in this context a given volume of river has the same recreational value as the same volume of lake water. This does not imply that rates of penalty will be equivalent, however. Modifying factors have been derived to adjust penalties with respect to the actual dispersal characteristics of the receiving water. These factors will be discussed in depth in a subsequent section of this chapter.

SELECTION OF CRITICAL VOLUME FOR COASTAL WATERS

Coastal waters also pose a major problem in terms of valuation. It is estimated that there are some 3.5×10^{11} cubic meters (2.8×10^{10} acre-feet) of water included in the twelve mile contiguous zone of the United States. These waters have direct effects on commercial fishing, a limited amount of sport fishing, boating, and recreational marine swimming.¹⁰ It is estimated that the total landed value of fishes from these waters is less than \$500 million annually." (This figure is based on the 1972 harvest of commercial species less \$200 million worth of estuarine dwelling shellfish). Annual receipts from swimming have been estimated at \$1.5 billion.⁹ If one assumes an infinite series of annual income at this level and a rate of interest of six percent, this is equivalent to a present worth of \$33 billion, or \$973 per million cubic meters (\$1.20 per acre-foot) of coastal water. On the other hand, pollution of these waters threatens the estuarine environment because of the continual interchange between the two. Therefore, additional value must be ascribed to coastal waters on the basis of their influence on estuaries. It is estimated that the Nation's estuaries include some 3.7×10^{11} cubic meters (3×10^8 acre-feet) of water [derived assuming an average estuarine depth of 3 meters (10 feet)].¹⁰ This is approximately one percent of the volume of coastal waters. At any one time, the interchange between coastal waters and an estuary is likely to approach a state of one-to-one mixing; that is, half of the water in the estuary is derived from coastal waters [based on tidal intrusion of 1.5 meters (5 feet), which is 50 percent of the 3 meters (10 feet) depth assumed]. The tidal interchange for the estuary of Grays Harbor, Washington, has actually been measured at 50 percent of the volume. Moreover, the average salinity of the Harbor is half that of typical coastal waters. Certainly, 50 percent is the right order of magnitude since in the extremes one can note

⁹National Oceanographic and Atmospheric Administration, National Marine Fisheries Service, Washington, DC, (unpublished data), May 1974.

¹⁰U. S. Department of Commerce, Development Potential of U. S. Continental Shelves, p. III-64, April 1966.

¹¹Battelle Memorial Institute, "The Economic and Social Importance of Estuaries," EPA, April 1971.

salt marshes with no freshwater input and estuaries at the mouth of major rivers where the salt is diluted to very low levels. Salinity is bounded on the low side by the ability of shellfish to survive in dilute solutions. The combined effect of these factors is such that 0.5 percent of contaminated coastal waters could potentially contaminate the estuaries. Thus, the value of coastal waters can be calculated by adding their intrinsic value, \$973 per million cubic meters (\$1.20 per acre-foot), and 0.5 percent of the value of estuarine waters, \$508 per million cubic meters (\$0.64 per acre-foot), to get \$1511 per million cubic meters (\$1.84 per acre-foot). This then becomes the basis for calculating the harmful quantity and rates of penalty to be employed for spills in coastal waters. The specific values and associated critical volumes with a value of \$5,000 are summarized for all water body types in Table IV-2.

TABLE IV-2
SPECIFIC VALUES AND ASSOCIATED CRITICAL
VOLUME WITH A VALUE OF \$5,000 FOR
THE FOUR BASIC WATER BODY TYPES

	Value	Critical Volume (\$5,000 value level)
Lake	\$0.07/cubic meter (\$83/acre-foot)	74,277 cubic meters (60 acre-feet)
River	\$0.07/cubic meter (\$83/acre-foot)	74,277 cubic meters* (60 acre-feet)
Estuary	\$0.10/cubic meter (\$127/acre-foot)	49,212 cubic meters (39 acre-feet)
Coastal Waters	\$1511/million cubic meters (\$1.84/acre-foot)	3.31 million cubic meters (2717 acre-feet)

*This is equivalent to one day's flow in a stream flowing at 2.04 cubic meters per second (30.2 cfs) and is tantamount to using a flow of 8.2 cubic meters per second (121 cfs) in the DOHM plug flow model developed in Chapter VII.

Once these levels have been selected, calculations can be made to derive the specific harmful quantity and rate of penalty for each hazardous material. Example calculations for freshwater lakes are illustrated in the following section.

EXAMPLE HARMFUL QUANTITY CALCULATIONS

Inherent in the Resource Value Methodology approach to designation of a harmful quantity is the assumption that some degree of environmental damage will be tolerated. The threshold level of damage to be employed has been selected as \$5,000 and freshwater lakes are valued at \$0.07 per cubic meter (\$83 per acre-foot). This means that the harmful quantity is defined as the amount of a material required to contaminate 74,277 cubic meters (60 acre-feet) of water (19,551,000 gallons). The amount of a hazardous material required to critically pollute this volume is the product of this volume of water and the critical concentration at which potential harm occurs. Similarly, the harmful quantities for the remaining three water body types can be calculated using the appropriate values from Table IV-2. These threshold levels have been calculated for the hazardous materials being evaluated:

Freshwater

Acetaldehyde = 53 ppm (96 hr TL_m for bluegill)

Cadmium Sulfate = 5.6 ppm as Cd (96 hr LC_{50} for fathead minnow)

Saltwater

Phenol = 24 ppm (48 hr LC_{50} for shrimp)

Hence, the respective harmful quantities (HQ) can be calculated for the various water body types as follows:

Acetaldehyde - Lake

$$\begin{aligned} HQ &= 19,551,000 \text{ (gal)} \times 53 \text{ (mg/l)} \times 8.3 \times 10^{-6} \text{ (lbs-l/mg-gal)} \\ &= 8700 \text{ lbs or } 3906 \text{ kg} \end{aligned}$$

Cadmium Sulfate - River

$$\begin{aligned} HQ &= 19,511,000 \text{ (gal)} \times 5.6 \text{ (mg/l)} \\ &\quad \times 8.3 \times 10^{-6} \text{ (lbs-l/mg-gal)} \\ &= 920 \text{ lbs or } 420 \text{ kg} \end{aligned}$$

Phenol - Estuary

$$\begin{aligned} HQ &= 12,708,150 \text{ (gal)} \times 24 \text{ (mg/l)} \times 8.3 \times 10^{-6} \\ &\quad \text{(lbs-l/mg-gal)} \\ &= 2541 \text{ lbs or } 1154 \text{ kg} \end{aligned}$$

Phenol - Coastal Zone

$$\begin{aligned} HQ &= 0.87 \times 10^9 \text{ (gal)} \times 24 \text{ (mg/l)} \times 8.3 \times 10^{-6} \\ &\quad \text{(lbs-l/mg-gal)} \\ &= 172,446 \text{ lbs or } 79,140 \text{ kg} \end{aligned}$$

INITIAL RATE OF PENALTY

The rate of penalty is defined as the value of potential damage to the environment. Since the harmful quantity is defined as the amount of a material required to damage \$5,000 worth of aquatic environment, the rate of penalty is simply

$$R \text{ of } P_0 = \$5,000/HQ.$$

This is considered only a starting point, however, since there are many receiving water influences and chemical characteristics which cause the probable damage to differ from the maximum potential damage. To account for the differences and subsequently adjust the rate of penalty, a modifying factor must be applied.

ADJUSTMENT FACTOR

It is recognized that the physical characteristics of many materials and receiving waters can prevent rapid dilution to threshold concentrations and indeed may allow for removal or destruction of a portion of the material. The formulation employed thus far, however, assumes instant mixing to an isoconcentration state at the critical concentration level which generates the maximum possible volume effected. Therefore, it is important to modify any rate of penalty determination by a factor which reflects the difference between maximum possible volume effected and the most probable volume affected. This adjustment factor has been designated r_k .

By definition, r_k must be comprised of both intrinsic and extrinsic components. Hence, the final rate of penalty ($R \text{ of } P_F$) is derived by operating on the original rate ($R \text{ of } P_0$) with the various r_k components:

$$R \text{ of } P_F = (R \text{ of } P_0) (r_k) = (R \text{ of } P_0) (r_k \text{ int}) (r_k \text{ ext})$$

With reference to the law, the intrinsic components reflect the concern for considering the degradability and dispersibility of the spilled material as mandated in Section 311(b)(2)(B)(iv), while the extrinsic components relate to the "...times, locations, circumstances, and conditions..." referred to in Section 311(b)(4). Both the intrinsic and extrinsic components can be further divided into individual factors as discussed below.

Intrinsic Factors

There are two factors of importance in the intrinsic component: one related to the persistence of the material and hence the duration of harmful effects, and one related to the ability of the material to spread in the environment at toxic levels.

The first factor, designated Anf, addresses the duration of the impact of a spill. In the derivation of the basic rate of penalty, volumes of water are associated with a value estimated as the total present worth to society of the water in a natural system. In many cases, setting rates of penalty at that high a level would be unfair since spills of most substances will devalue the water for a finite time period but not destroy it forever. To reflect this, the Anf, or annuity factor, has been devised to convert the base rate of penalty to one commensurate with the present worth of an annuity lasting for the number of years over which the impact of the spill is likely to persist. The yearly amount of the annuity is set at the level which taken over an infinite life at six percent interest would yield the present worth estimated for the water or, put more simply, six percent of the present worth value now associated with the water. For example, freshwater is valued at a present worth of \$0.07 per cubic meter (\$83 per acre-foot) so the amount of the annuity would be $\$0.07 (.06) = \$0.0042$ per cubic meter per year [$\$83 (.06) = \$5$ per acre-foot per year]. The annuity factor would then be the present worth of \$0.0042 per cubic meter per year (\$5 per acre-foot per year) for x years where x is the period over which the impact persists. This can be reduced to the form:

$$\text{Anf} = \frac{\text{Pwa} (6\%, x \text{ yrs})}{\text{Pwa} (6\%, \infty \text{ yrs})}$$

where

Anf = annuity factor

Pwa = present worth factor

x = impact period for material spilled

Pwa (6%, ∞ yrs) = 16.7

Each material is then classified according to the potential duration of effects from an acute spill. The material's classification is associated with a time span which then defines x for a spill of that material. The values of x selected for each classification of hazardous materials are presented in Table IV-3.

No material is credited with an impact duration of less than one year. While the acute lethality may be exhibited in a few short hours, one year is considered a reasonable requirement for repopulation. For example, when fly ash was discharged into the Clinch River, it was estimated that it would take a full summer for benthic life to return to normal population levels.¹¹

¹¹"Clinch River Fish Kill, June 1967," U. S. Department of the Interior, Federal Water Pollution Control Administration, Middle Atlantic Region, Charlottesville, VA, June 1967.

TABLE IV-3

IMPACT PERIODS ASSIGNED TO MATERIAL CLASSIFICATIONS FOR
USE IN DERIVING THE A_{nf} FACTOR (PERIODS GIVEN IN YEARS)

Material Classification	Water Body Type			
	Lake	River	Estuary	Coastal Zone
Organic - Degradable	2	1	3	1
Persistent	3	1	4	2
Bioconcentrative	5	3	5	2
Inorganic - Bioconcentrative	5	2	5	2
Nonbioconcentrative	2	1	3	1

When additional time is added to account for higher trophic levels, one full season of recreational activities is essentially lost.

Longer impact periods have been assigned to lakes where aeration and repopulation processes may be slower. A minimum impact period of three years has been attributed to estuaries where non-mobile shellfish species require the extra time to reach maturity.

Bioconcentrative materials have been assigned a five year impact period for the more static water bodies where environmental cycling and accumulation in the food chain can extend the potential effects of a spill over a long period. While workers in Sweden have estimated that mercury contaminated lakes in that country may require 100 years to cleanse themselves,¹² natural sedimentation and chemical processes are likely to inactivate spilled materials in a much shorter time. Work with toxaphene¹³⁻¹⁵ has revealed that impact times are

¹²Jernelov, A. "Conversion of Mercury Compounds," Chemical Fallout, Chapter 4, Thomas Springfield Co., 1969.

¹³Johnson, W. D., G. F. Lee, D. Spyridakis. "Persistence of Toxaphene in Treated Lakes," Air & Water Pollution Int. Journal, Pergamon Press, Volume 10, 1966.

highly varied, but usually do not exceed five years. Similar work in estuaries gave comparable results.¹⁶ Persistent materials are credited with impact periods between the two extremes. The shorter effect times accredited to coastal water spills reflect a result of ocean dumping studies in the Gulf-Coast area.¹⁷

The present worth factors (Pw) for the associated annuities and the consequent Anf Factors are given in Table IV-4.

From the table it can be seen that the spill of a persistent organic into a lake will result in a base rate of penalty (R of P_B) approximately one sixth the estimated present worth of the water potentially affected:

$$R \text{ of } P_B = (R \text{ of } P_O) (.16)$$

Similarly, if the material had been bioconcentrative, the rate of penalty would be one quarter the base rate of penalty since the Anf would be 0.25.

The second factor in the intrinsic component is one related to the inherent ability of the material to spread through the environment at toxic levels. It has been designated Disp and must consider both the physical/chemical properties of the material (such as specific gravity, solubility, and volatility) as well as the critical resources which would potentially be damaged in a given type of water body. In order to assign factors, the materials were categorized into groupings based on their predicted response to spillage in water. A multidisciplinary panel of scientists from the Pacific Northwest Laboratories of Battelle Memorial Institute was then asked to assign Disp factors for spillage of a classification of material into a specific water body type. Miscible substances were identified with a Disp of 1.0 to act as the base comparator for

¹⁵Cushing, C. E. Jr. and J. R. Olive. "Effects of Toxaphene and Rotenone Upon the Macroscopic Bottom Fauna of Two Northern Colorado Reservoirs," transactions of the American Fisheries Society.

¹⁵Gebhards, S. V. "A Review of Toxaphene for Use in Fish Eradication," prepared for State of Idaho, Department of Fish and Game, March 3, 1960.

¹⁶Reimold, R. J., P. C. Adams and C. J. Curant. Effects of Toxaphene Contamination on Estuarine Ecology, Georgia Marine Science Center, Technical Report Series No. 73-8, September 1973.

¹⁷Battelle Memorial Institute. Program for the Management of Hazardous Wastes, EPA, Contract No. 68-01-0762, July 1973.

TABLE IV-4
PRESENT WORTH OF ANNUITY AND Anf FACTORS ASSOCIATED
WITH THE SELECTED IMPACT DURATION PERIODS

Material Classification	Water Body							
	Lake		River		Estuary		Coastal Zone	
	PWa*	Anf	PWa	Anf	PWa	Anf	PWa	Anf
Organic - Degradable	1.83	0.11	0.94	0.06	2.67	0.16	0.94	0.06
Persistent	2.67	0.16	0.94	0.06	3.47	0.21	1.83	0.11
Bioconcentrative	4.21	0.25	2.67	0.16	4.21	0.25	1.83	0.11
Inorganic - Bioconcentrative	4.21	0.25	1.83	0.11	4.21	0.25	1.83	0.11
Nonbioconcentrative	1.83	0.11	0.94	0.06	2.67	0.16	0.94	0.06

*Pwa refers to present worth factor at 6% for X years where X is the impact period assigned to each classification in Table IV-2.

the four water types. The subsequent factors were then selected to rate other categories on the basis of their propensity to spread more or less than a miscible substance and to affect the most critical sector of the host environment. The results of the panel's independent scoring are presented in Table IV-5.

For the purpose of the classification process, the following definitions were employed:

- miscible - liquid substances which can freely mix with water to any proportions or have a solubility >1,000,000 ppm
- mixes - solid substances which freely mix with water or have a solubility >1,000,000 ppm
- precipitates - salts which disassociate in water with the subsequent precipitation of the toxic ion
- insoluble, volatile, floats - materials lighter than water with a vapor pressure >10 mm Hg and a solubility <1,000 ppm or materials with solubility <10,000 and vapor pressure >100 mm Hg
- insoluble, nonvolatile, floats - materials lighter than water with a vapor pressure <10 mm Hg and solubility <1,000 ppm
- soluble, floats - materials lighter than water and solubility >1,000 ppm
- insoluble, sinks - materials heavier than water and solubility <1,000 ppm
- soluble, sinks - materials heavier than water and solubility >1,000 ppm

Several specific interpretations can be seen from Table IV-4. In general, miscible substances were felt to have the maximum potential for spreading in the critical sector of the environment. The three exceptions were sinking and precipitating materials in estuaries where shellfish are a major factor in the value of the resource. Floating substances received somewhat higher ratings than those which sink in coastal waters because of the surface transport processes which would bring spills into the beach and estuarine zones.

The individual factors that make up the intrinsic component are multiplicative and, consequently, the total intrinsic component is defined as

$$rk \text{ int} = (Anf) (Disp)$$

TABLE IV-5
RELATIVE Disp FACTORS FOR VARIOUS WATER BODY TYPES

Material Classification	Water Body Type			
	Lake	River	Estuary	Coastal Zone
Miscible	1.0	1.0	1.0	1.0
Mixes	0.84	0.80	0.84	0.78
Precipitates	0.73	0.71	1.3	0.55
Insoluble, Volatile, Floats	0.31	0.31	0.27	0.35
Insoluble, Nonvolatile, Floats	0.74	0.62	0.60	0.94
Soluble, Floats	0.86	0.86	0.82	0.86
Insoluble, Sinks	0.59	0.58	1.35	0.43
Soluble, Sinks	0.83	0.85	1.05	0.59

Individual intrinsic component values for each of the designated hazardous substances are detailed in Appendix C.

Extrinsic Factors

The extrinsic component is similar to the intrinsic component in that it too is derived as the produce of two individual factors: ResU, the resource use modifier and Loc, the locational dispersion factor. Thus,

$$rk \text{ ext} = (\text{ResU})(\text{Loc})$$

The extrinsic factors are designed for selection after the fact. They serve to adjust the penalty to align it more closely with actual damages.

The resource use modifier is designed to reflect the extent to which the spill site environment deviates from the average employed to derive the original rate of penalty; that is, it recognizes that a broad range of values can be attributed to a single water body depending upon the type and extent of use it sustains. Hence, if a water body does not presently sustain a healthy aquatic community, penalties for spills will be adjusted downward, while penalties for spills in high use recreational water bodies will be elevated. Ideally then, the ResU factor is derived by dividing the estimated present worth of the receiving water by the value used for the base rate of penalty. Therefore, if the estimated present worth is X per cubic meters, one uses

$$\text{Lake - ResU} = \frac{X}{.07}$$

$$\text{River - ResU} = \frac{X}{.07}$$

$$\text{Estuary - ResU} = \frac{X}{.10}$$

$$\text{Coastal Water - ResU} = \frac{X}{.0015}$$

If annual values for the damaged resource are known, the present worth at six percent used previously can be converted to annual values by dividing the denominator by 16.7. Consequently, for an annual value of \$Y per cubic meter, the corresponding ResU factors are:

$$\text{Lake - ResU} = \frac{Y}{.0042}$$

$$\text{River - ResU} = \frac{Y}{.0042}$$

$$\text{Estuary - ResU} = \frac{Y}{.006}$$

$$\text{Coastal Water - ResU} = \frac{Y}{.00009}$$

It is recognized that for many water bodies, the annual values or present worth values will not have been estimated. In the event of a spill into these waters, ResU factors can be obtained directly from Figure IV-5.

The values employed here were derived largely from the charts presented in Figures IV-3 and IV-5.

The location dispersion factor, Loc, is formulated to adjust the rate of penalty to take into account the natural dispersive forces in the receiving water. The basic model assumes instantaneous mixing to an isoconcentrative state at the critical concentration. This clearly leads to the use of the maximum potential volume affected as the volume damaged by a spill. In actuality, material dispersion patterns will lead to smaller volumes of affected water. To account for this, Loc has been defined as:

$$\text{Loc} = \frac{\text{predicted actual volume}}{\text{instantaneous mix maximum volume}}$$

For each application, then, it is desirable to construct a set of matrices yielding Loc, the ratio of the two volumes. This would then allow quick selection of the appropriate Loc factor for any given spill. In order to derive the numerator, the predicted volume, one must employ a quantitative formulation. A computerized hydrodynamic model was selected for this purpose. Parameters were then selected for use as independent variables in the model.

Two criteria were applied in selecting input parameters for the various water body types:

1. The parameters should be significant with respect to effects on the dispersion of a spill into the water body type of interest, and
2. The parameters should be either well catalogued values available on many potential receiving waters or should be subject to close estimation by on-scene personnel.

Utilizing these criteria, the following selections were made:

Lake - average depth and angle of descent from the shoreline to the point of average depth. Advective currents were assumed to be 0.11 kilometers per hour (0.1 fps) parallel to the shoreline and nil in the other directions.

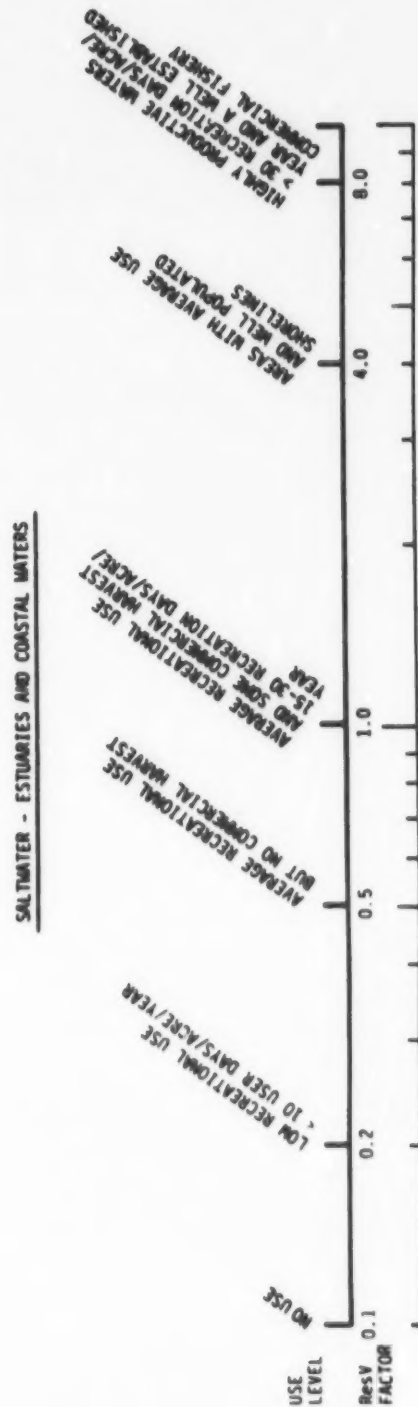
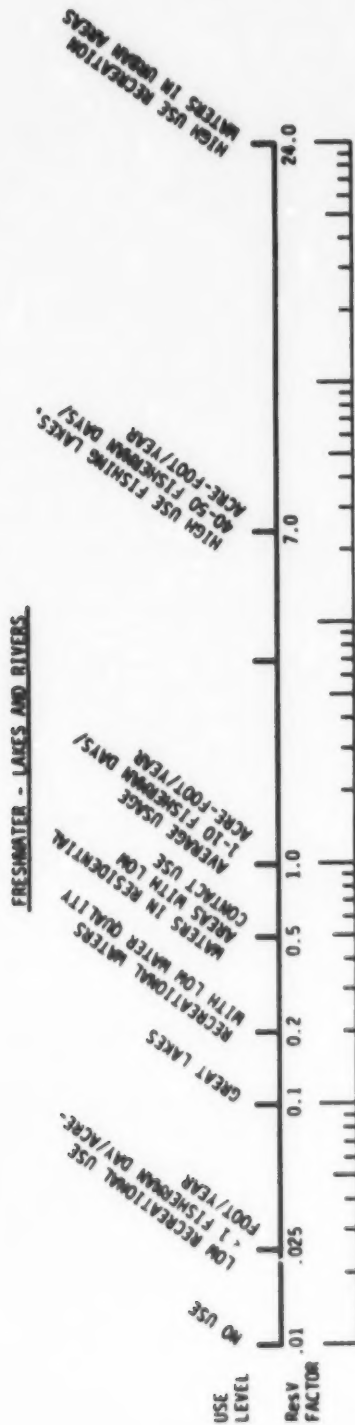


FIGURE IV-5. VALUATION CHARTS FOR ASSIGNING ResV FACTORS TO WATERS OF UNKNOWN VALUE

River - flow rate and flow velocity. These two parameters are subsequently used in Ward Type Equations to derive physical dimensions to be employed as boundaries in the model. Dispersion coefficients are also varied as a function of flow rate and velocity.

Estuary - models for estuarine systems could not be simplified to two variables without designating where in the estuary the spill occurs. Consequently, it is recommended that the model be used for all spills except those outside the major current pattern where the coastal water model should be employed.

Coastal Waters - average current velocity and average depth. The depth, however, is generally too great to act as a barrier to dispersion. Consequently, it is held constant and only the current velocity is varied.

The model employed focused on developing a semi-analytical solution to the governing equation considering variable diffusion coefficients, transforms, Green's function, and the method of image sources to avoid the finite differences approach. The model is described in detail in Appendix D.

Output from the model is the volume of water (V) contained by the isoconcentration lines at a given critical concentration level (CC) for a fixed quantity of spilled material (M). The maximum volume attainable with instant mixing is simply

$$V_{max} = M/CC$$

Therefore, the location factor becomes

$$Loc = V/V_{max}$$

$$= V/M/CC = V(CC)/M$$

These dimensionless fractions are tabulated in Appendix D for the various parameter combinations employed. It should be noted that the ratio of volumes changes when different concentration levels are employed as the critical concentration. Consequently, adjustment relations have been approximated from the output of discrete model runs. These relations are also explained in Appendix D. It is also important to note that no model is applicable to all water bodies. Therefore, individual LOC factors are not important so much as the order of magnitude they occur at. For instance, the data tabulated suggests that spills in lakes and coastal waters will threaten only about 18 percent of the maximum possible volume of water while for spills in rivers and estuaries the rates is closer to 3.6 percent. These numbers were obtained as the average of those presented in Appendix D after extreme conditions, e.g., 90° angle of descent were discarded.

Summary

In summary, rates of penalty should be a function of both intrinsic factors related to the substance spilled and extrinsic factors related to the site of the spill. While the intrinsic factors can be assessed extant and thus are included in the base rate of penalty for each hazardous substance, the extrinsic factors require varying degrees of on-scene evaluation. These post spill determinations, however, have been simplified through the development of nomographs and matrices from which the appropriate adjustment factors can be quickly selected.

It must be recognized that no attempt has been made to define r_k as a natural phenomenon. Rather, the r_k factor is designed merely as a transform to produce the appropriate effects on the rate of penalty under varying conditions. Thus, rather than describing underlying universal interrelations, the r_k relations merely provide a desired transform for modification of rates of penalty from values representing maximum potential damage to those representing probable or actual damage.

DETERMINATION OF THE FINAL RATE OF PENALTY

The final rate of penalty will be set such that the incremental penalty per unit of measurement approximates the value of the environment potentially damaged by the spill. This is done by taking the product of the value of the environment, \$0.07 per cubic meter (\$83 per acre-foot) for lakes and rivers; the volume of environment contaminated by the harmful quantity, 74,277 cubic meters (60 acre-feet) per HQ for lakes and rivers; and the adjustment factor r_k , or more simply, \$5,000/HQ. Hence, the final rate of penalty, R of P_F is

$$R \text{ of } P_F = (\text{value/unit environment}) (\text{critical volume/HQ}) (r_k)$$

$$R \text{ of } P_F = (\$5,000/\text{HQ}) (r_k)$$

The extrinsic components cannot be added until after the fact. The intrinsic ones can, however, be employed at this time to establish the base rate of penalty (R of P_B). Example calculations are made below:

Acetaldehyde - Lakes

$$R \text{ of } P_B = 83 (\$/\text{acre-foot}) \times 60/4.3 (\text{acre-feet/ton}) \times (.11) \times (1.0)$$

$$R \text{ of } P_B = \$128/\text{ton} = \$141/\text{metric ton}$$

Cadmium Sulfate - Rivers

$$R \text{ of } P_B = 83 (\$/\text{acre-foot}) \times 60/908 (\text{acre-feet/lb}) \times (.11) \times (.71)$$

$$R \text{ of } P_B = \$0.43/\text{lb} = \$0.94/\text{kg}$$

Phenol - Estuaries

$$R \text{ of } P_B = 127 (\$/\text{acre-foot}) \times 39/2541 (\text{acre-feet/lb}) \times (.16) \times (1.05)$$

$$R \text{ of } P_B = \$33/100 \text{ wt} - \$0.73$$

To illustrate how the extrinsic factors are brought into the formulation, consider the case where the acetaldehyde spill occurred in a residential lake with low water contact usage, an average depth of 7.6 meters (25 feet), and an angle of descent of 45°. From Figure IV-8, the ResU factor is determined to be 0.5. From Appendix D, the Loc factor for a critical concentration of 50 can be taken as that for a concentration of 5 times the ratio of that for 10 to that for 1, or

$$\text{Loc}_{50} = \left(\frac{\text{Loc}_{10}}{\text{Loc}_1} \right) (\text{Loc}_5) = \left(\frac{.078}{.074} \right) (.061) = .064.$$

Therefore, the final rate of penalty, R of P_F , can be determined as $R \text{ of } P_F = R \text{ of } P_B \times (\text{rk ext})$.

$$R \text{ of } P_F = \$202/\text{ton} \times 0.5 \times .064$$

$$R \text{ of } P_F = \$6.46/\text{ton} = \$7.12/\text{metric ton}.$$

Base rates of penalty without consideration for extrinsic factors and harmful quantities as derived by the Resource Value Methodology are compared to those resulting from the other methodologies in Appendix N. It is apparent that if the economic rational is to be maintained, penalty rates must be reviewed periodically and adjusted to reflect changes in resource values and/or monetary fluctuations.

REFERENCES

1. Personal communication, Thomas Maloney, EPA/NERC, Corvallis, OR, February 13, 1974
2. Grad, F. A Treatise on Environmental Law, §2.03, 2-166, 1973.
3. Personal communication, Dr. A. L. Jennings, EPA/Division of Oil and Hazardous Materials, Washington, DC, July 24, 1974.
4. "Water Policies for the Future," final report to Congress of the National Water Commission, USGPO, June 1973.
5. "Environmental Quality - 1974," Fifth Annual Report of the Council on Environmental Quality, Washington, DC, USGPO, December 1974.
6. Todd, D. K. The Water Encyclopedia, the Maple Press Company for the Water Information Center, 1970.
7. Sullivan, C. R. "Economic and Social Significances of Sport Fishing," National Conference on Complete Water Reuse, AICHE-EPA Technology Transfer Series, April 23-27, 1973.
8. National Oceanographic and Atmospheric Administration, National Marine Fisheries Service, Washington, DC, (unpublished data), May 1974.
9. U. S. Department of Commerce, Development Potential of U. S. Continental Shelves, P. III-64, April 1966.
10. Battelle Memorial Institute, "The Economic and Social Importance of Estuaries," EPA, April 1971.
11. "Clinch River Fish Kill, June 1967," U. S. Department of the Interior, Federal Water Pollution Control Administration, Middle Atlantic Region, Charlottesville, VA, June 1967.
12. Jernelov, A. "Conversion of Mercury Compounds," Chemical Fallout, Chapter 4, Thomas Springfield Co., 1969.
13. Johnson, W. D., G. F. Lee, D. Spyridakis. "Persistence of Toxaphene in Treated Lakes," Air & Water Pollution Int. Journal, Pergamon Press, Volume 10, 1966.
14. Cushing, C. E. Jr. and J. R. Olive. "Effects of Toxaphene and Rotenone Upon the Macroscopic Bottom Fauna of Two Northern Colorado Reservoirs," transactions of the American Fisheries Society.

15. Gebhards, S. V. "A Review of Toxaphene for Use in Fish Eradication," prepared for State of Idaho, Department of Fish and Game, March 3, 1960.
16. Reimald, R. J., P. C. Adams and C. J. Curant. Effects of Toxaphene Contamination on Estuarine Ecology, Georgia Marine Science Center, Technical Report Series No. 73-8, September 1973.
17. Battelle Memorial Institute. Program for the Management of Hazardous Wastes, EPA, Contract No. 68-01-0762, July 1973.

V. THE MODIFIED IMCO/GESAMP METHODOLOGY

BRIEF

In this approach, hereafter referred to as the IMCO Methodology, a procedure is developed for designating harmful quantities and rates of penalty based on a proposed international hazardous material rating/classification system which has been submitted under the auspices of the United Nations to its member nations for adoption. When adopted, it is anticipated that this system will be used to regulate the operational discharges of ships transporting liquid noxious substances in bulk. The hazardous material rating/classification system upon which the IMCO Methodology is based was originally developed by an ad hoc committee of IMCO and GESAMP experts as part of an international effort to bring about regulations that would reduce pollution of the sea resulting from the discharges (both intentional and accidental) of ocean-going vessels.

These regulations, like Section 311, are intended to bring about a reduction in the release of hazardous materials to the environment; however, the concepts of harmful quantity and rate of penalty are not present in these regulations and hence, modification of the basic IMCO system is necessary in order to construct a methodology which complies with the requirements of Section 311. More specifically, the IMCO rating/classification system provides a mechanism for differentiating between materials on the basis of their various hazard potentials. The methodology developed below uses this differentiation as a basis for deriving harmful quantities and rates of penalty.

As an overview, the IMCO Methodology first utilizes the rating/classification system developed by the committee of experts to profile noxious substances (which may be considered hazardous materials) on the basis of their relative hazard potentials. These profiles are then used to relegate the hazardous materials to hazard categories depending upon the degree to which they are expected to exert their various hazard potentials. Once materials have been relegated to one of the four categories, a critical concentration is derived for each category. These critical concentrations are taken to be representative of the levels at which the hazardous materials in a given category are expected to present a substantial threat to the aquatic environment in a spill situation. The resource value approach derived in Chapter IV is then used to derive a critical volume of water (a volume which, when contaminated to the critical concentration, results in substantial harm) for each of the four general water body types being considered by this study. These critical volumes when multiplied by the critical concentrations yield harmful quantities for each category in each water body type. Base rates

of penalty are then computed by utilizing the ratio of the value of the water to the mass of hazardous material required to contaminate the water to its critical concentration. For each designated material, the base rate of penalty is then modified by an adjustment factor which considers the ability of the material to exert its full hazard potential(s) in a given water body type when consideration is given to the physical/chemical properties of the material. Adjustment factors are derived through the use of a DELPHI technique. The designated materials are also profiled with respect to their physical/chemical properties so that appropriate adjustment factors can be assigned to each material. For reader convenience, the steps in developing the IMCO Methodology are shown schematically in Figure V-1.

IMCO/GESAMP REPORT ON THE IDENTIFICATION OF NOXIOUS AND HAZARDOUS SUBSTANCES

General

The Inter-Governmental Maritime Consultative Organization (IMCO) is the depository of the International Convention for the Prevention of Pollution of the Sea by Oil, 1954, which is committed to examine the possibilities of formulating, in cooperation with other United Nations agencies, suitable international agreements aimed at preventing and controlling all pollution resulting from activities of ships, craft, and equipment operating in the marine environment. The Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) is an advisory body composed of experts from a number of international organizations including the Food and Agricultural Organization (FAO); the United Nations Educational, Scientific and Cultural Organization (UNESCO); the World Meteorological Organization (WMO); the International Atomic Energy Agency (IAEA); the World Health Organization (WHO); the United Nations (UN); and IMCO.

In preparing for an International Conference on Marine Pollution to be held in 1973, the IMCO Subcommittee on Marine Pollution noted certain difficulties in utilizing the categories of pollutants previously identified by GESAMP for developing control measures for operational discharges and for the construction and equipment of ships carrying dangerous chemicals in bulk. To resolve these difficulties, an ad hoc panel of IMCO and GESAMP experts was convened to prepare a rated list of noxious and hazardous substances for subsequent approval by GESAMP at its fourth session. The work of the ad hoc panel resulted in the submission of a report¹ to the fourth session of GESAMP held at

¹"Report of an Ad Hoc Panel of IMCO and GESAMP Experts to Review the Environmental Hazards of Noxious Substances Other Than Oil Transported by Ships," Joint Group of Experts on the Scientific Aspects of Marine Pollution, London, England, 1972/73.*

*Also contained in the congressional hearing report, "Hearing Before the Committee on Commerce on 1973 IMCO Conference on Marine Pollution from Ships, November 1973," U. S. Senate, 93rd Congress, First Session, Series 93-52.

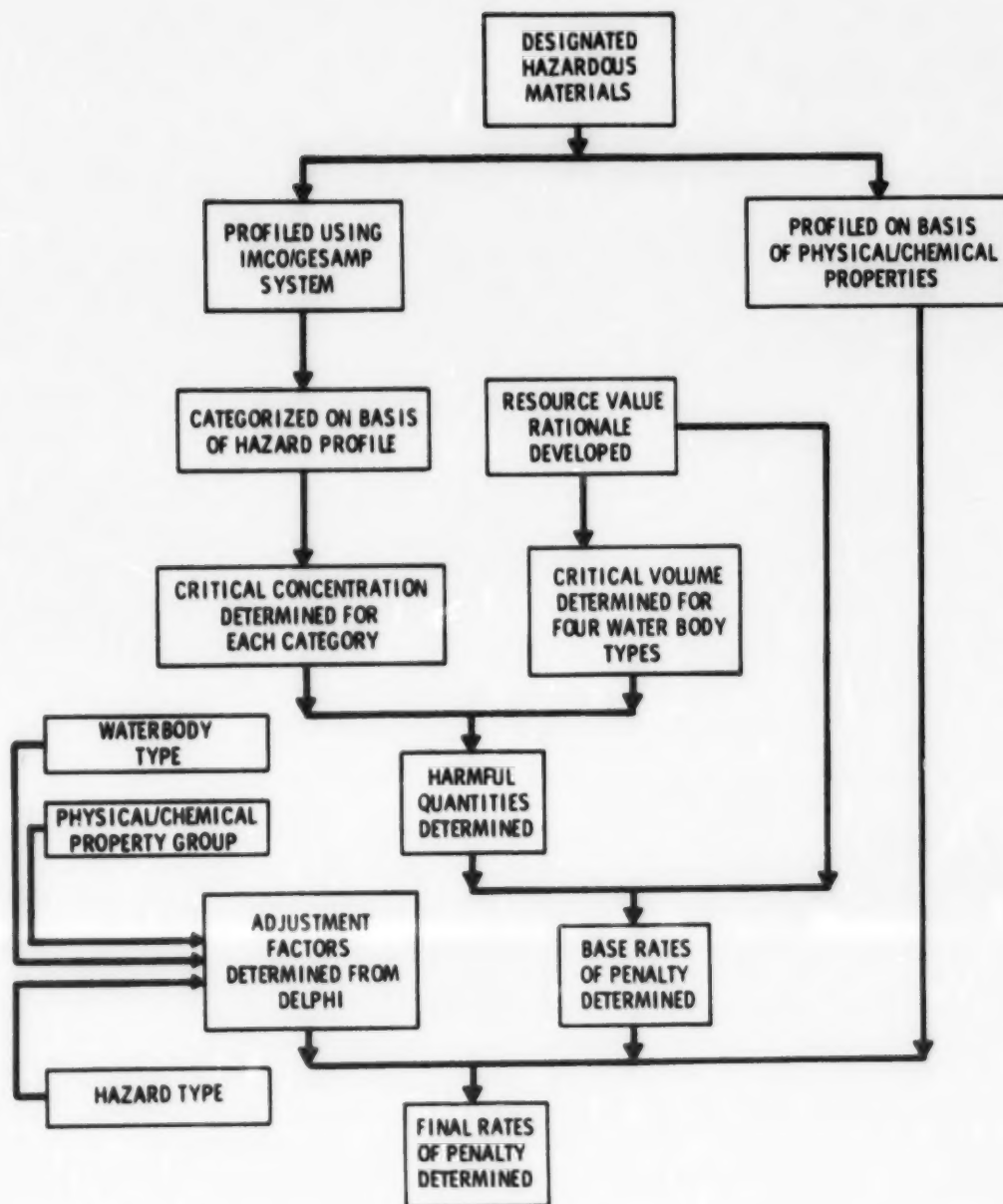


FIGURE V-1. FLOW DIAGRAM FOR IMCO METHODOLOGY

WMO Headquarters, Geneva, Switzerland, September, 18-23, 1972. In this report, a system for profiling hazardous materials on the basis of their various hazard potentials was put forth along with individual profiles on almost 400 hazardous materials evaluated by the ad hoc committee. This report was adopted by the fourth session of GESAMP.

At the 1973 International Conference on Marine Pollution, the system developed by the ad hoc committee was used to draft regulations for the control of pollution by noxious liquid substances transported in bulk. These proposed regulations² provide the foundation upon which the methodology described in this section is based.

The IMCO System

The system developed by the ad hoc committee and later endorsed by GESAMP is one which characterizes or profiles hazardous materials shipped by water in bulk quantities. Specifically, the chemicals considered were "all noxious and hazardous substances other than oil"¹ as defined by the 1954 Oil Pollution Convention. The report characterizes these noxious materials with respect to five hazard potentials:

- Bioaccumulation
- Damage to living resources
- Hazards to human health (oral intake)
- Hazards to human health (external exposure)
- Reduction of amenities

Appendix E contains a listing of these hazard potentials along with the rating system used to differentiate degrees of hazard within each hazard potential. Also included in this appendix is a sample page from the report which shows how this system was used to profile individual chemicals.

At the time of this report, no attempt was made by the ad hoc committee to select extremely hazardous materials out of those being currently shipped. Rather, their task was to develop a rationale for evaluation any substance which was carried as a bulk liquid, dry, or package cargo. Details of the procedures adopted by the committee for evaluating the substances are documented in their report¹ along with discussions of problem areas

² "Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk, Annex II," International Conference on Marine Pollution, October 31, 1973.*

*Also contained in the congressional hearing report, "Hearing Before the Committee on Commerce on 1973 IMCO Conference on Marine Pollution from Ships, November 1973," U. S. Senate, 93rd Congress, First Session, Series 93-52.

such as quantifying bioaccumulation potential and compromise areas such as substituting animal LD₅₀ values to determine the hazard to human health. The reader is referred to the primary document for these details.

The report of the ad hoc committee of experts was accepted by the fourth session of GESAMP (1972/73), subject to the following important technical considerations.

1. The Group recognized and approved that, in the absence of sufficient data on lethal threshold concentrations, it had been necessary to use LC₅₀ values. It was stressed that there is limited biological significance in such values and that evaluation of the threshold concentrations is preferable and should be encouraged.
2. The Group cautioned that there was a real possibility that the hazard ratings would be used for purposes other than those specified in the IMCO inquiry. To elaborate, it was felt that before the rationale and its table of ratings could be used for other purposes, it would be necessary to include additional or more detailed information particularly with respect to physical properties, bioaccumulation characteristics, persistency in the marine environment, long term effects on the balance of the ecosystem, and the transformation reactions of certain substances.
3. Some views were expressed concerning the interpretation of hazard ratings of substances which bioaccumulate and which might be repeatedly discharged in a given area.
4. The need for establishing a mechanism for continually updating the list of substances was emphasized.

Since the ultimate goal of this undertaking was the development of a set of regulations for the control of pollution by noxious substances, it was necessary to extend the original work of the ad hoc committee. This task was performed by government representatives operating as a working group under the IMCO Marine Pollution subcommittee. Their work was eventually incorporated into "Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk",² a document adopted by the 1973 International Conference on Marine Pollution. The work of the subcommittee centered around categorizing the subject noxious materials based on the hazard profiles developed by the ad hoc committee as shown in Appendix E. Four categories of hazardous materials were developed by the subcommittee.²

- Category A - Noxious liquid substances which, if discharged into the sea from tank cleaning or deballasting operations, would present a major hazard to either

marine resources or human health or cause serious harm to amenities or other legitimate uses of the sea and, therefore, justify the application of stringent anti-pollution measures.

- Category B - Noxious liquid substances which, if discharged into the sea from tank cleaning or deballasting operations, would present a hazard to either marine resources or human health or cause harm to amenities or other legitimate uses of the sea and, therefore, justify the application of special anti-pollution measures.
- Category C - Noxious liquid which, if discharged into the sea from tank cleaning or deballasting operations, would present a minor hazard to either marine resources or human health or cause minor harm to amenities or other legitimate uses of the sea and, therefore, require special operational conditions.
- Category D - Noxious liquid substances which, if discharged into the sea from tank cleaning or deballasting operations, would present a recognizable hazard to either marine resources or human health or cause minimal harm to amenities or other legitimate uses of the sea and, therefore, require some attention in operational conditions.

NOTE: Authors' underlines for emphasis.

Technical guidelines for these categories are contained in Appendix F. These guidelines are based on the previous work of the IMCO ad hoc committee and reflect the deliberations of the 1973 International Convention on Marine Pollution.²

Under the regulations adopted by IMCO, various operational and record keeping constraints are placed on ships employed in the transport of the subject noxious substances. These constraints vary with the category of the material, the most severe constraints being associated with Category A materials and the least severe constraints with Category D materials.

Applicability of the IMCO System to Determining Harmful Quantities and Rates of Penalty for Hazardous Material Spills

Utilization of the IMCO system has the apparent advantage of providing a ready-made system in which the characterization and categorization of hazardous materials has already been accomplished by a body of experts representing an international awareness of technical information. Hence, a methodology based on this system carries in part the support of the credentials of the international body of experts who formulated and approved the system as well as the concerns of their governments which are

in the process of approving the convention. The acceptance of such a methodology based on an internationally recognized classification system is perhaps more likely than one which has not been subjected to prior scrutiny. In addition, the advantage of domestic regulations which are compatible with an international convention should not be overlooked.

From a conceptual and operational viewpoint, an IMCO based methodology which considers hazard groups rather than individual chemicals offers the advantage of simplicity relative to other methodologies especially in terms of reporting and fine determination. Despite these advantages, the fact remains that the IMCO system was not developed or intended to be used as a basis for determining harmful quantities and rates of penalty for hazardous material spills. Specific drawbacks include those listed below.

- The IMCO system is specific to a marine environment whereas the rates of penalty and harmful quantity regulations must apply to freshwater as well as salt-water bodies.
- Although the IMCO system is capable of profiling and categorizing any material, only liquid substances shipped in bulk were categorized in Annex II of the proposed international regulations.² As a result, about 75 percent of the substances considered in this study have not been categorized under the IMCO system. Although the guidelines (see Appendix F) for categorizing the hazardous substances are fairly clear, it is also known that some degree of subjectivity entered into the discussions of the IMCO subcommittee. Consequently, the profiling and categorization of 75 percent of the designated materials cannot fully duplicate the work of the international body of experts.
- Rigorous or formal consideration of the physical/chemical (as opposed to the toxicological) properties of the hazardous materials is not evident in the IMCO system. Section 311 requires that "degradability and dispersal"³ characteristics be considered in determining rates of penalty. Hence, modification of the existing IMCO system to include formal consideration of physical/chemical properties is necessary.
- Although the IMCO system does offer a basic framework for categorizing hazardous materials, it does not provide a ready mechanism for quantitating differences

³Public Law 92-500 and 92nd Congress of the United States, October 18, 1972.

between categories. Since Section 311 requires that specific harmful quantities and rates of penalty be promulgated, definite numerical differences between categories must be determined.

Modification of the IMCO System

In light of the foregoing discussion, some modifications of the IMCO system are required in order to develop a viable methodology for determining harmful quantities and rates of penalty. The following required modifications have been identified.

- Hazardous materials which have already been profiled and categorized must be reexamined in terms of their freshwater hazard potential.
- Unprofiled and uncategorized hazardous materials must be evaluated for both fresh- and saltwater hazard potentials. The guidelines contained in Appendices E and F form the basis for this work.
- Physical/chemical properties (specifically, degradability and dispersibility) must be taken into account to modify or adjust the rate of penalty.
- A mechanism for quantitatively differentiating between the IMCO categories must be devised in order to derive harmful quantities and rates of penalty.

THE IMCO METHODOLOGY FOR DETERMINING HARMFUL QUANTITIES AND RATES OF PENALTY

Profiling and Categorization of Hazardous Materials

Under the IMCO Methodology, hazardous materials are profiled and categorized in two separate ways. The first profile is in strict accordance with the IMCO system and results in a characterization of the relative hazard potentials associated with each material. The IMCO/GESAMP guidelines for the profiling of hazardous materials are contained in Appendix E. Individual profiles of materials considered by this study are contained in Appendix G.

Based on the profiles generated in Appendix E, the hazardous materials were assigned to hazard categories. The IMCO/GESAMP guidelines for categorizing hazardous materials are contained in Appendix F. Appendix G shows the category to which each hazardous material was assigned as well as the basis for assignment to that category. Appendix H lists hazardous materials by category.

The profiling operation considers the bioaccumulative, toxicological, irritant, and aesthetic properties of the hazardous material in terms of the level of hazard associated with each material under each of the five hazard potentials. As such, the system provides guidelines for quantitative differentiation between materials within each profile heading but not across profile headings. This means that within each of the five hazard potential categories (see Appendix E) clear-cut guidelines have been established for identifying the relative magnitude of the particular hazard for any given material. For example, the potential to damage living resources is assessed on the basis of 96 hour LC₅₀. Materials having mean 96 hour aquatic toxicities of 1 ppm or less are considered to be highly toxic while materials with 96 hour LC₅₀'s ranging between 1 and 10 ppm are considered moderately toxic. Although the selection of these ranges was somewhat arbitrary, it is still possible to assign appropriate ratings to each material on the basis of known "numbers" (e.g., 96 hr LC₅₀'s, LD₅₀'s), and because these ratings are numerical in nature, various means of quantitative comparison are possible. On the other hand, when comparing across hazard potentials (e.g., bioaccumulation versus moderate damage to living resources), one is faced with comparing unrelated factors. More precisely, there exists no reasonable common denominator which allows one to compare or relate the various hazard potentials in a quantitative and rigorous fashion.

Because of this problem, the IMCO and GESAMP experts were forced to resort to certain value judgments in order to devise a system which grouped hazardous materials with the recognized capability of exerting multiple hazard effects. These value judgments are manifest in the definitions of the four hazard categories contained in Appendix F. Referring to this appendix, the reader will see that in Category A, for example, a value judgment has been made which says that hazardous materials which are either bioaccumulated, highly toxic to aquatic life, or tainting and moderately toxic to aquatic life pose the same relative degree of hazard. Thus in accepting the IMCO based methodology, one must accept these value judgments which are an integral part of the IMCO system. It should be noted that these value judgments were affected by a variety of international interests including environmental, scientific, commercial, political, economic, and social at the 1973 convention.

The second profiling operation in this phase was based on the physical/chemical properties of the hazardous materials. This was necessary because the IMCO rating system affords little recognition to these properties which in many instances can have a substantial effect on the ability of the hazardous materials to exert their full hazard potential. More precisely, the IMCO system, by itself, provides a "worst case" assessment of the

hazards associated with various materials. This is an unavoidable consequence of the data base for this system (e.g., 96 hr LC₅₀'s, LD₅₀'s, bioconcentration factors). However, in a spill situation the ability of a given hazardous material to exert its full hazard potential is constrained by the degree to which it is able to reach and persist in the critical areas of the environment.

As a first step in determining the degree to which the physical/chemical properties of hazardous materials affect their hazard potential it was necessary to profile the materials in a manner which would indicate their general pattern of action following a spill into a natural water body.

Four properties were selected as being the most meaningful in terms of predicting general action patterns:

- Persistence
- Behavior Classification (Float, Mix, Sink)
- Volatility
- Solubility

These properties are most precisely defined in Appendix I. In Appendix G, each material is profiled with respect to these four properties. The full significance of these profiles is explained in the next section.

Quantifying Differences Between Hazard Categories and Physical/Chemical Characteristics

The proposed IMCO regulations² provide guidelines for the operation of ships engaged in the transport of hazardous materials. In this respect, the differences between the four IMCO categories are functionally defined in terms of the degree to which operating restrictions are placed on the carriers. However, this type of differentiation is not adequate for determining harmful quantities and rates of penalty. Rather a more quantitative form of differentiation is required.

In this study the four IMCO hazard categories (A through D) were differentiated on the basis of critical concentration. Each category was assigned a critical concentration based on the mean aquatic toxicity (96 hr LC₅₀) range representative of that category (see Appendix F). Critical concentrations for each category are given in Table V-1.

TABLE V-1

IMCO CATEGORY CRITICAL CONCENTRATIONS

<u>IMCO Category</u>	<u>Representative Aquatic Toxicity Range (ppm)</u>	<u>Assigned Critical Concentration (ppm)</u>
A	<1	0.5
B	1-10	5.5
C	10-100	55
D	100-500*	300

*The IMCO criterion for Category D aquatic toxicity is 96 hr LC₅₀ values of 100-1000 ppm. The selection criteria for materials considered in this study eliminated any material with a 96 hr LC₅₀ in excess of 500 ppm. Thus, the representative toxicity range for Category D materials has been changed to 100-500 ppm for use in this study.

The primary reasons for selecting aquatic toxicity as the basis for differentiating between hazard categories is that it is the only criterion common to all four categories and, therefore, the only one which permits a quantitative comparison of categories without some form of additional subjective evaluation between different hazard potentials (e.g., bioaccumulation vs reduction of amenities). Furthermore, the aquatic toxicity data along with the oral toxicity data is the most complete and best documented set. However, the oral toxicity data (primarily derived from animal studies) is only indirectly applicable since it is used to approximate the threat to man through oral ingestion. The aquatic toxicity data, on the other hand, is directly applicable. Finally, in the vast majority of spills, the most probable and observable damages will be in terms of fish-kill or some other form of damage to aquatic life.

As alternatives to selecting the mean value of the aquatic toxicity range for each category, mean, median, and modal values of the materials comprising each category were also considered for determining the critical concentrations of each category. All of these alternatives were rejected. From an operational point of view, any of these alternatives would require the recomputation of the critical concentration every time a new material was added to the category. This in turn would necessitate a recomputation of the harmful quantity and a subsequent adjustment of the rate of penalty. Moreover, in light of the wide variations encountered

in the aquatic toxicity data, it is unreasonable to expect that by utilizing these median, modal or average values any meaningful enhancement of the category's critical concentration would be realized.

The second profiling operation (Appendix G) characterized the hazardous materials on the basis of their physical/chemical properties. This was done as a first step in attempting to answer a very important, though rather intractable, question common to all methodologies:

To what extent does the dispersibility and degradability of a given hazardous material reduce or enhance its ability to exert its full potential?

A precise determination of the answer to this question, even for a set of very specific circumstances, is, of course, impossible because of incomplete understanding of the environment and the forces acting therein. When extended to the general case (e.g., lakes in general vs a specific lake whose physical, chemical, biological, and hydrodynamic properties are well understood), the problem becomes even more difficult. Nevertheless, it must be addressed.

The approach taken in the IMCO Methodology was to derive subjective adjustment factors (on a scale of 0 to 1) which could be assigned to a material with a given set of physical/chemical properties. These adjustment factors give recognition to the ability of a material's physical/chemical properties to affect its hazard potential(s) in various water body types and this can be factored directly into the rate of penalty as a mechanism which accounts for a material's dispersibility and degradability characteristics.

The procedure used to obtain adjustment factors was the DELPHI method.⁴ This procedure involves the repeated questioning of persons knowledgeable in the area of interest in order to obtain a coalescence of expert opinion. The DELPHI method makes use of controlled opinion feedback and thus avoids direct confrontation of the experts with one another. Between rounds of questioning, the participants are "fed" the results of the previous round and advised of the opinions which were voiced by other panel members. In subsequent rounds, the question posed may also be restated in slightly different terms especially if ambiguities surrounding the question are causing wide variations in the results. By repeating this sequence a number of times, a coalescence of opinion is obtained in an environment of controlled participant interaction.

⁴Dalkey, N. and O. Helmer. "An Experimental Application of the DELPHI Method to the Use of Experts," Management Science, Vol. 9, No. 3, 1963.

The panel for this DELPHI consisted of a group of scientists and engineers selected from the staff of Battelle's Pacific Northwest Laboratory. This panel was asked to assign a series of adjustment factors based on their estimation of how various sets of physical/chemical properties would affect the ability of a material with these properties to exert a given hazard potential in a given water body type. The details of this DELPHI are contained in Appendix I along with a table depicting the resulting adjustment factors. As will be seen in the "Fine Determination" section of this chapter, these adjustment factors are applied to a base rate of penalty in order to obtain a formal rate of penalty.

Determining the Harmful Quantity

In this methodology harmful quantities must be determined for the four hazard groups in the four water bodies. This means that 16 harmful quantities are generated by this methodology. As in the other methodologies, a prerequisite to determining a harmful quantity is the definition of the term "harm." More precisely, the harmful quantity determination requires that a threshold level of harm be defined in such a way that it can be related quantitatively to the hazardous materials and their various hazard potentials. Since each IMCO hazard category is represented by a critical concentration, the threshold level of harm (or the criteria for defining harm) must be relatable to the critical concentration.

The approach taken in this methodology for determining the threshold level of harm is identical to the Resource Value Methodology approach. Harm is defined as \$5,000 worth of damages. The rationale for using \$5,000 is discussed in Chapter IV of this report. Having defined the threshold level of harm in terms of dollars it is then possible to relate this dollar value to a critical volume of water if the unit value of water is known.

$$V \text{ critical} = \$5,000/\text{unit value of water body} \quad (V-1)$$

The harmful quantity is then computed by multiplying the critical concentration by the critical volume.

Table V-2 contains the IMCO Methodology harmful quantities. These values were obtained using the critical concentrations reported in Table V-1 in conjunction with the critical volumes computed from equation V-1. Unit values used for the determination of critical volume in the four water body types (derived in Chapter IV) are as follows:

- Lake - $\$0.07/\text{m}^3$ (\$83/AF)

TABLE V-2
IMCO METHODOLOGY HARMFUL QUANTITIES*

IMCO Category	Water Body Type			
	Lake	River	Estuary	Coastal Zone
A	3.7×10^1 kg	3.7×10^1 kg	2.6×10^1 kg	1.4×10^3 kg
	8.3×10^1 lbs	8.3×10^1 lbs	5.4×10^1 lbs	3.1×10^3 lbs
B	4.1×10^2 kg	4.1×10^2 kg	2.7×10^2 kg	1.5×10^4 kg
	8.1×10^2 lbs	9.1×10^2 lbs	6.1×10^2 lbs	3.4×10^4 lbs
C	4.1×10^3 kg	4.1×10^3 kg	2.7×10^3 kg	1.5×10^5 kg
	9.1×10^3 lbs	9.1×10^3 lbs	6.1×10^3 lbs	3.4×10^5 lbs
D	2.3×10^4 kg	2.3×10^4 kg	1.5×10^4 kg	8.5×10^5 kg
	4.9×10^4 lbs	4.9×10^4 lbs	3.2×10^4 lbs	1.9×10^6 lbs

*Rounded to two significant figures

- River - $\$0.07/\text{m}^3$ (\$83/AF)
- Estuary - $\$0.10/\text{m}^3$ (\$127/AF)
- Coastal Zone - $\$1,511/10^6 \text{ m}^3$ (\$1.84/AF)

It is noteworthy that the IMCO Methodology harmful quantity can be computed on the basis of any threshold level of harm if this threshold can be related to the critical volume of water. Since the definition of harm will, in all likelihood, continue to be a controversial issue, this degree of flexibility promises to be a valuable asset in that it allows for the easy recomputation of harmful quantities while preserving the basic tenets of the methodology. This versatility is also available in recomputing the rate of penalty as evidenced in the next section.

Determining the Base Rate of Penalty

The IMCO Methodology bases its rate of penalty on predicted damages to the environment and follows directly from the harmful quantity determination in the previous section. Harmful quantities were derived by using a threshold dollar value of \$5,000 in conjunction with average present worth values for water body types and critical concentrations for each category. Using this rationale, the harmful quantity (HQ) can be viewed as that amount of material capable of producing \$5,000 worth of damages to the environment. It follows that the rate of penalty should be set at \$5,000/HQ. Since there are 16 harmful quantities, one for each category in each water body type, 16 rates of penalty are possible. These rates of penalty are more appropriately labeled base rates of penalty as certain modifications are required to account for the dispersibility and degradability characteristics before a final rate of penalty can be determined. These modifications are explained in the next section.

Fine Determination

A step by step procedure for computing fines under the IMCO Methodology is outlined below.

In this procedure, the fine for a given hazardous material becomes a function of three variables:

- The quantity spilled,
- The base rate of penalty ($\$5,000/\text{HQ}$), and
- The adjustment factor (AF) where $\frac{\$5,000}{\text{HQ}} \times \text{AF}$
is the final rate of penalty.

On a conceptual basis, the spiller is being fined for the predicted damages to the water body (\$5,000/HQ) with consideration (AF) given to the ability of the of the spilled material to exert its various hazard potentials. The three cases (a, b, c) consider the three situations which can cause a hazardous material to be placed in a given hazard category. Note that in case b the final adjustment factor may exceed a value of one. Hence, materials capable of exerting multiple hazards of the same order of magnitude (same category) will in most instances receive higher rates of penalty.

The procedure for determining fines under the IMCO Methodology is as follows:

1. Determine the name and quantity (M) of hazardous material spilled.
2. Determine the type of water body (w_i) into which the hazardous material was spilled.
3. Determine the hazard category (hc_j) of the material from Appendix G.
4. Determine the hazard potential(s) (c_k) which caused the material to be placed in hazard category (hc_j). This is also determined from Appendix G.
5. Determine the physical/chemical characteristics (pc_l) of the material from Appendix G.
6. Determine the adjustment factor(s) [$AF(w_i, c_k, pc_l)$] by entering the table in Appendix I with the hazard potential(s) (c_k), water body type (w_i), and physical/chemical characteristic (pc_l).
7. Determine the harmful quantity [$HQ(w_i, hc_j)$] for the material in water body type (w_i). Consult Table V-2 for this number.
8. Compute the fine from one of the following formulas:
 - a) If there is only one hazard potential (c_k) which caused the material to be placed in hazard category (hc_j) then

$$\text{Fine} = M \times [\$5,000/HQ_{(w_i, hc_j)}] \times [AF(w_i, c_k, pc_l)]$$

- b) If there is more than one hazard potential (c_k) in Appendix G which by itself could cause the material to be placed in hazard category (hc_j) then

$$\text{Fine} = M \times [\$5,000/\text{HQ}(w_i, c_k, pc_1)] \times \left[\sum_{k=1}^n \text{AF}(w_i, c_k, pc_1) \right]$$

and n is the number of hazard potentials which, by themselves, could cause the material to be placed in category (hc_j).

- c) If the material was placed in category (hc_j) as a result of the additive effects of various hazard potentials any one of which by itself is insufficient to cause the material to be placed in the category then

$$\text{Fine} = M \times [\$5,000/\text{HQ}(w_i, hc_j)] \times \frac{\left[\sum_{k=1}^n \text{AF}(w_i, c_k, pc_1) \right]}{n}$$

where n is the number of hazard potentials which, when considered together, caused the material to be placed in category (hc_j).

Final rates of penalty for each hazardous material have been computed in Appendix M.

Sample Calculations

Sample fine calculations for three hazardous materials in three water body types are provided below:

Case 1 - Acetaldehyde spilled into a lake

Material: acetaldehyde

Water body type: lake

Hazard category: C

Hazard potential which caused it to be placed in Category C: damage to living resources

Physical/chemical
characteristics: nonpersistent, floats, volatile, soluble

Adjustment factor: 0.3

Harmful quantity: $4.1 \times 10^3 \text{ kg}$
($9.0 \times 10^3 \text{ lbs}$)

$$\text{Rate of penalty} = \frac{\$5,000}{4.1 \times 10^3 \text{ kg}} \times 0.3 = \frac{\$366}{10^3 \text{ kg}}$$

$$= \frac{\$5,000}{9.1 \times 10^3 \text{ lbs}} \times 0.3 = \frac{\$165}{10^3 \text{ lbs}}$$

Case 2 - Cadmium sulfate spilled into a river

Material: cadmium sulfate

Water body type: river

Hazard category: A

Hazard potential which
caused it to be placed
in Category A: bioaccumulation

Physical/chemical
characteristics: persistent, sinks, soluble

Adjustment factor: 0.8

Harmful quantity: $3.7 \times 10^1 \text{ kg}$
 $8.2 \times 10^1 \text{ lbs}$

$$\text{Rate of penalty} = \frac{\$5,000}{37 \text{ kg}} \times 0.8 = \$108/\text{kg}$$

$$= \frac{\$5,000}{83 \text{ lbs}} \times 0.8 = \$48/\text{lb}$$

Case 3 - Phenol spilled into an estuary

Material: phenol

Water body type: estuary

Hazard category: B

Hazard potential which
caused material to be
placed in Category B: tainting (bioaccumulation)

Physical/chemical
characteristics: nonpersistent, mixes

Adjustment factor: 0.45*

Harmful quantity: 2.7×10^2 kg
 5.9×10^2 lbs

Rate of penalty = $\frac{\$5,000}{2.7 \times 10^2 \text{ kg}} \times 0.45 = \$84/10 \text{ kg}$

= $\frac{\$5,000}{6.1 \times 10^2 \text{ lbs}} \times 0.45 = \frac{\$38}{10 \text{ lbs}}$

Harmful quantities and rates of penalty as determined by the IMCO Methodology for designated hazardous substances are tabulated in Appendix M. It is apparent that if the economic rational is to be maintained, penalty rates must be reviewed periodically and adjusted to reflect changes in resource values and/or monetary fluctuations.

*Since no adjustment factor was determined for nonpersistent "bioaccumulation" materials, an adjustment factor of 0.45 based on aquatic toxicity was used because of its similarity of action to tainting.

REFERENCES

1. "Report of an Ad Hoc Panel of IMCO and GESAMP Experts to Review the Environmental Hazards of Noxious Substances Other Than Oil Transported by Ships," Joint Group of Experts on the Scientific Aspects of Marine Pollution, London, England, 1972/73.
2. "Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk, Annex II," International Conference on Marine Pollution, October 31, 1973.
3. Public Law 92-500 and 92nd Congress of the United States, October 18, 1972.
4. Dalkey, N. and O. Helmer, "An Experimental Application of the DELPHI Method to the Use of Experts," Management Science, Vol. 9, No. 3, 1963.

VI. THE UNIT OF MEASUREMENT METHODOLOGY

BRIEF

The methodology developed below is a variation of the IMCO Methodology discussed in the previous chapter but more importantly it represents a radical conceptual departure from the other methodologies.

This methodology is intended to satisfy the letter of the law (Section 311) whereas the other methodologies in this report utilize a technical or economic basis to satisfy the intent of the law. The derivation of this methodology is based upon the selection of a unit of measurement. Harmful quantities and rates of penalty are then derived from this unit of measurement whose prime selection criteria are that it (1) be a unit common to usual trade practices, and (2) be large enough so that spillage of this quantity leaves little doubt that substantial harm will result. Rates of penalty are also derived from this unit of measurement by forming a ratio with the fixed monetary amount set by Congress in Section 311. Hence, the emphasis in this methodology is away from the concepts of a harm threshold and costs relatable to an economic or technical basis and toward a system whose units are more in line with trade practices and the letter of the law.

For purposes of identification, this methodology will be referred to hereafter as the Unit of Measurement (UM) Methodology. Figure VI-1 provides a schematic representation of the UM Methodology which should facilitate reader understanding of ensuing sections.

METHODOLOGY RATIONALE

In the other methodologies, an attempt has been made to develop systems that derive harmful quantities and rates of penalty in a logical and relatively rigorous sequence of steps after certain necessary simplifying assumptions have been made. For example, the approach to determining substantial harm has been one of defining a threshold of harm either statistically or pragmatically, relating this threshold to a volume of water, and then deriving the harmful quantity by calculating the amount of a given hazardous material required to contaminate this volume to its critical concentration. Similarly, rates of penalty have been derived as entities in themselves either on the basis of prevention costs or the value of the resource potentially damaged. Conceptually, both of these derived rates of penalty have direct economic meaning in that the ratio formed by the dollar value (X) and the mass of pollutant spilled (Y) are functionally related. For example, when the cost of prevention is employed, the basic rate of penalty is set at a level

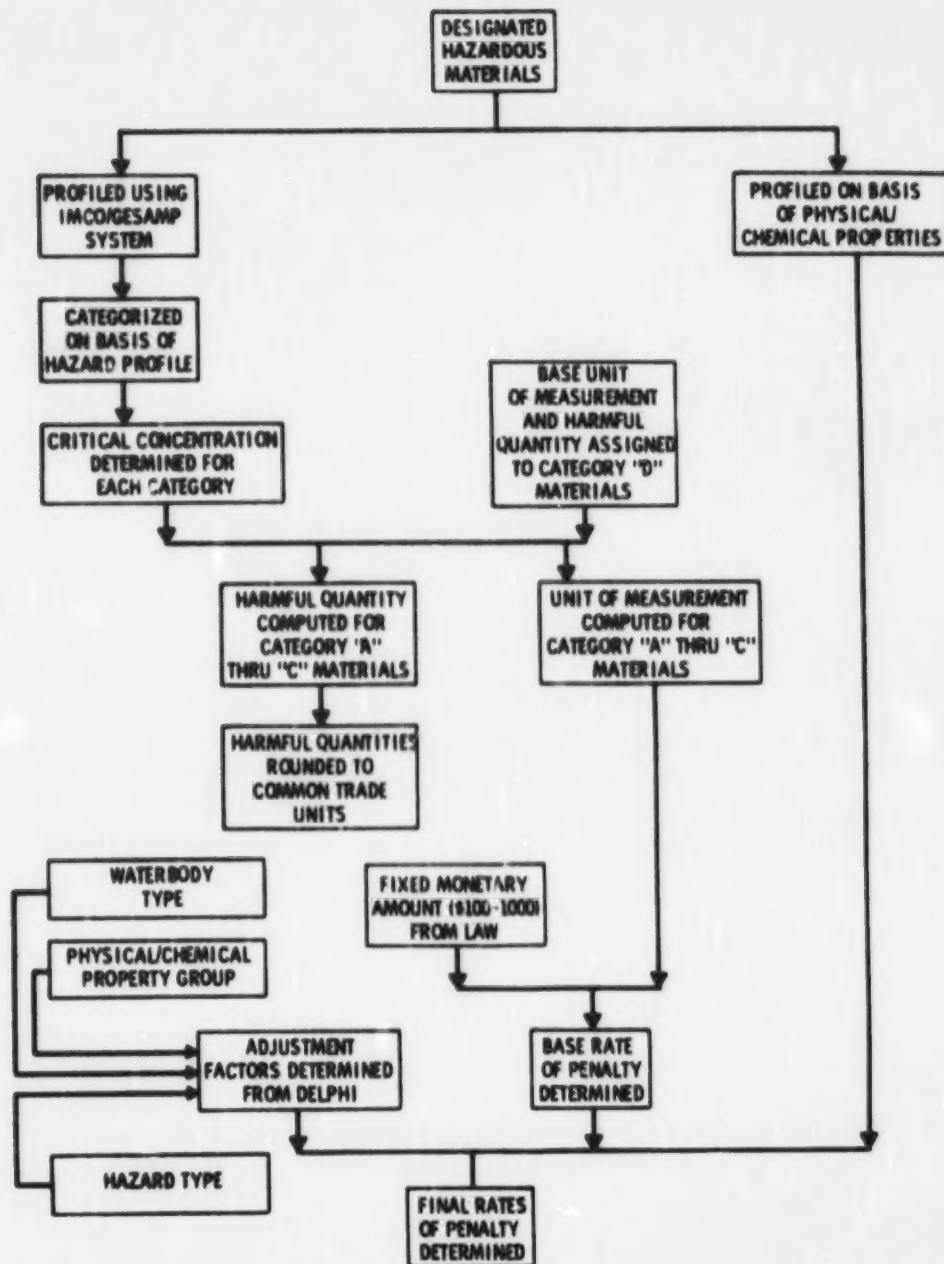


FIGURE VI-1. FLOW DIAGRAM FOR UNIT OF MEASUREMENT METHODOLOGY

deemed necessary to provide adequate economic incentive for the institution of spill prevention measures. Theoretically, X dollars expended result in a reduction of spillage equal to Y. Similarly, the Resource Value Methodology produces a rate of penalty equal to the value of damages incurred and thus internalizes the cost to society of spillage. The spillage of Y units of hazardous material results in X dollars worth of damages, this amount being reimbursed to society through the fine system.

The UM Methodology departs significantly from other approaches in two important conceptual areas. First, the harmful quantity, previously derived from a threshold concept, is herein equated to a base unit of measurement which is selected large enough so that there is little doubt that spillage of this amount will result in substantial harm. Thus, on the spectrum of possible harmful quantities, a point is selected to yield a harmful quantity which is no less than (but possibly greater than) the quantity which actually does produce substantial harm when spilled into a water body.

The second area of major departure is in selection of the basis for the rate of penalty. As discussed previously, the UM Methodology merely selects a unit of measurement based on trade practices and relates it to the monetary amount fixed by Congress. In this respect, the methodology is supported by the wording of the law:

"The Administrator shall establish by regulation, for each hazardous substance designated under subparagraph (A) of this paragraph, and within 180 days of the date of such designation, a unit of measurement based upon the usual trade practice and, for the purpose of determining the penalty under clause (iii)(bb) of this subparagraph, shall establish for each such unit a fixed monetary amount which shall be not less than \$100 nor more than \$1,000 per unit. He shall establish such fixed amount based on the toxicity, degradability, and dispersal characteristics of the substance."

Public Law 92-500, Section 311(b)(2)(B)(iv)

Indeed, this paragraph strongly implies that the rate of penalty be derived by forming a ratio between a unit of measurement based on usual trade practices and the fixed monetary amount (\$100-\$1,000) specified by Congress.

The UM Methodology is similar to the other methodologies in the terms of the procedures used to differentiate between hazardous materials on the basis of toxicity, degradability, and dispersibility. Here the inputs used to make these differentiations

will be the same as those described in the discussion of the alternative approaches (e.g., 96 hr LC₅₀, LD₅₀). Since this discussion is primarily illustrative, the authors have simply extracted the IMCO procedures for making this differentiation rather than developing a completely unique set of guidelines. The IMCO procedures were selected on the basis of their compatibility with the low levels of resolution inherent in the UM approach.

UNIT OF MEASUREMENT AND HARMFUL QUANTITY DETERMINATION

Referring to Figure VI-1, one can see that the initial steps in the UM Methodology are identical to those of the IMCO Methodology. Hazardous materials are profiled and assigned to one of four hazard categories on the basis of their various hazard potentials. A critical concentration is then assigned to each hazard category. Concurrently, the hazardous materials are profiled on the basis of their physical/chemical properties. This step is required in order to be able to assign an adjustment factor to each material in the final fine determination step.

The next step, and also the point of departure from the IMCO Methodology, is the selection of a base unit of measurement. Understandably, this selection can be rather arbitrary since the condition which the unit of measurement must meet is that it be a unit "common to the usual trade practice." For purposes of this illustration, the authors have chosen to select the unit of measurement from a group of common containers used in the transportation of hazardous materials. Figure VI-2 portrays some of the more common container sizes used by industry to ship hazardous materials. Viewing this figure, one can see that the containers fall into two basic groups: small individually packaged units such as metal cans and drums, and larger bulk shipment containers such as tank trucks and barges. One can also observe that there is a significant break (in terms of quantity) between the two groups with the largest individual container being a 110 gallon metal drum and the smallest bulk container being a 4000 gallon tank truck. This break provides a convenient point of demarcation for establishing a unit of measurement and a harmful quantity.

If one considers IMCO Category D materials, which are characterized as being recognizably hazardous, one would probably be hard pressed to show that the spillage of 110 gallons (the largest packaged container size) of such material would result in substantial harm. However, one would expect almost unanimous agreement as to the ability of 4000 gallons of a Category D material to produce substantial harm in many spill situations. To verify this assertion, consider the spillage of 4000 gallons of formic acid (a Category D material) into a freshwater lake or river.

The volume of water (V critical) potentially affected is determined as follows:

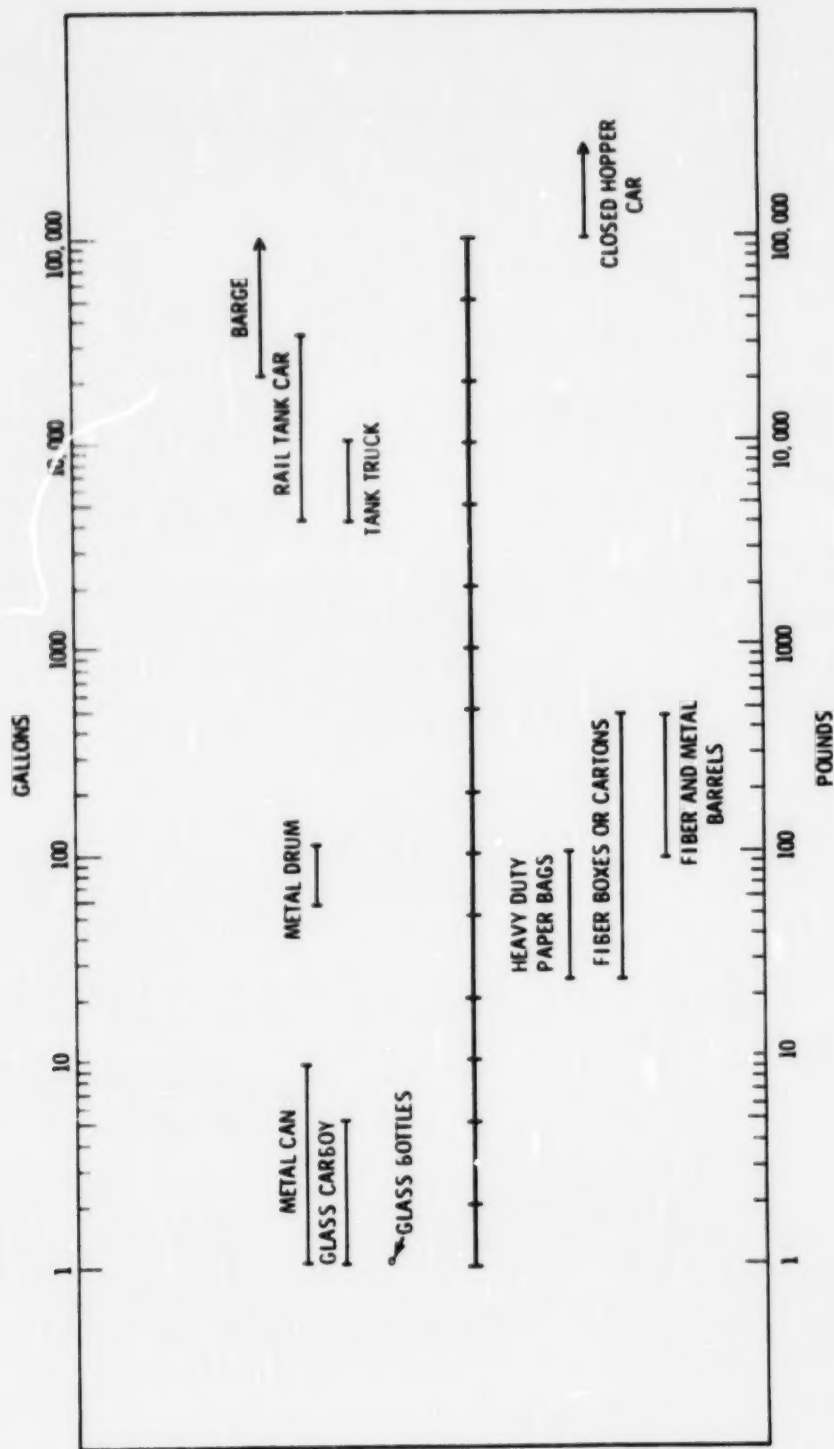


FIGURE VI-2. COMMON HAZARDOUS MATERIAL CONTAINERS

Assumptions:

Spill size = 4000 gal of 90% formic acid (S.G. = 1.22)

Freshwater critical concentration = 175 ppm (24 hr TL_m
for bluegill)

The mass of pollutant spilled is

$$4000 \text{ gal} \times 1.22 \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \frac{.453 \text{ kg}}{\text{lbs}} \times .9 = 1.65 \times 10^4 \text{ kg}$$

The volume potentially contaminated is

$$V \text{ critical} = \frac{1.65 \times 10^4 \text{ kg}}{1.75 \times 10^2 \text{ mg/l}} = 9.4 \times 10^7 \text{ l}$$

or

$$V \text{ critical} = 9.4 \times 10^7 \text{ l} = 3.32 \times 10^6 \text{ ft}^3 = 76 \text{ acre-feet}$$

or

V critical = a 7.6 acre lake with an average depth of
10 feet or a 6.3 mile long plug in a river
with a cross-sectional area of 100 ft².

Thus by defining substantial harm as the spilling of 4000 gallons of a Category D material, a harmful quantity is set for which there is a high probability that the spillage of such a quantity results in substantial harm although it is possible that spillage of a smaller amount could also produce substantial harm. Furthermore, by using this approach harmful quantities can be designated in units which are common to the usual trade practice for Category D substances. As shown below, harmful quantities for the remaining categories of hazardous substances can be similarly designated.

Table VI-1 lists the critical concentrations assigned to each IMCO category. By forming a ratio of the critical concentrations of Category A through C materials to the critical concentration for Category D materials, a numerical factor can be obtained which reflects the ability of hazardous materials in the first three categories to contaminate natural waters relative to Category D materials. Hence, harmful quantities and units of measurement can be assigned to the Categories A through C materials by simply multiplying these numerical factors by the base unit of measurement/harmful quantity previously selected for Category D materials.

Since harmful quantity is a threshold reporting function, it is advisable to round off the computed values to units that are more

TABLE VI-1
CALCULATION OF UNITS OF MEASUREMENT AND
HARMFUL QUANTITIES FOR IMCO CATEGORIES

IMCO Category	Critical Concentration (ppm)	Ratio of Critical Concen- tration to Category D Critical Concentration	Calculated Unit of Mea- surement and Harmful Quantity (Volume)	Calculated* Unit of Mea- surement and Harmful Quantity (Mass)
A	0.5	.0016	24.23 l 6.40 gal	24.23 kg 53.41 lbs
B	5.5	.0183	277.1 l 73.2 gal	277.1 kg 610.9 lbs
C	55.0	.1833	2,770 l 732 gal	2,770 kg 6,107 lbs
D	300.0	1.0000	15,142 l 4,000 gal	15,142 kg 33,382 lbs

*Calculated assuming an average specific gravity of 1.

easily ascertained in a spill situation. Table VI-2 contains the recommended harmful quantities for the four IMCO categories. Rounding was performed in the English system and metric equivalence computed from the rounded English numbers.

TABLE VI-2
RECOMMENDED HARMFUL QUANTITIES

IMCO Category	Harmful Quantity (volume)	Harmful Quantity (mass)
A	>5 gal >18.93 l	>50 lbs >22.7 kg
B	>55 gal >208.20 l	>500 lbs >227 kg
C	>550 gal >2081.98 l	>5000 lbs >2267.96 kg
D	>4000 gal >15.41 m ³	>16 tons >14.5 MT

COMPUTING THE BASE RATE OF PENALTY

In the UM Methodology, the base rate of penalty is determined from the ratio formed by the unit of measurement computed in Table VI-1 (Column 3) and a dollar amount of \$1000. The (\$1000) upper limit of the dollar range (\$100-\$1000) specified by Congress was selected because, as will be seen in the next section, in most instances the adjustment factors* for dispersibility and degradability are proportioned to reduce the base rate of penalty up to one order of magnitude (0.1-1.0). The base rates of penalty for the UM Methodology are computed using equation VI-1 and are summarized in Table VI-3.

Fine Determination

The step by step procedure for computing fines under the UM Methodology is outlined below.

In this procedure, the fine for a given hazardous material becomes a function of three variables:

- the quantity spilled (M)
- the base rate of penalty (\$1000/unit of measurement)
- the adjustment factor (AF)

*Identical to IMCO Methodology adjustment factor (see Appendix I)

$$\text{Base Rate of Penalty} = \frac{\$1000}{\text{Computed Unit of Measurement (Table VI-1)}}$$

(VI-1)

where (Base Rate of Penalty) x AF is the final rate of penalty.

TABLE VI-3

BASE RATE OF PENALTY

<u>IMCO Category</u>	<u>Base Rate of Penalty (volume)</u>	<u>Base Rate of Penalty (mass)</u>
A	\$410/10 l \$156/gal	\$410/10 kg \$186/10 lbs
B	\$360/100 l \$136/10 gal	\$360/100 kg \$163/100 lbs
C	\$360/1000 l \$ 136/100 gal	\$360/1000 kg \$163/1000 lbs
D	\$661/10 m ³ \$250/1000 gal	\$661/10 MT \$600/10 tons

As in the IMCO Methodology, adjustment factors (AF) derived from the DELPHI technique (Appendix I) are applied to the base rate of penalty to yield a final rate of penalty. These adjustment factors account for the degradability and dispersal characteristics of a given hazardous material by considering the degree to which its physical/chemical properties affect its ability to exert a given hazard potential(s) in a given water body type. In most instances the adjustment factor tends to reduce the base rate of penalty. Adjustment factors are assigned to each material on the basis of its physical/chemical profile in Appendix G.

Thus, in the UM Methodology, the discharger is being fined at the rate of penalty with consideration given to the effects of the spilled material's physical/chemical properties. The three cases (a, b, c) consider the three different ways a hazardous material can be placed in a given hazard category.

Note that in case b, additive effects (multiple hazard potentials of the same order of magnitude) can cause the adjustment factor to exceed a value of one. The procedure for computing fines under the UM Methodology is as follows:

1. Determine the name and quantity (M) of hazardous material spilled.
2. Determine the hazard category (hc_j) of the material from Appendix G.
3. Determine the base rate of penalty from Table IV-3.
4. Determine the type of water body (w_i) into which the hazardous material was spilled.
5. Determine the hazard potential(s) (c_k) which caused the material to be placed in hazard category (hc_j).
6. Determine the physical/chemical characteristics (pc_1) of the material from Appendix G.
7. Determine the adjustment factor(s) ($AF(w_i, c_k, pc_1)$) by entering the table in Appendix I with the hazard potential(s), (c_k); water body type, (w_i); and physical/chemical characteristics, (pc_1).
8. Compute the fine from one of the following formulae:
 - a. If there is only one hazard potential (c_k) which caused the material to be placed in hazard category (hc_j), then

$$\text{Fine} = M \times (\text{Base Rate of Penalty}) \times \left(AF(w_i, c_k, pc_1) \right)$$

- b. If there is more than one hazard potential (c_k) in Appendix G which by itself could cause the material to be placed in hazard category (hc_j), then

$$\text{Fine} = M \times (\text{Base Rate of Penalty}) \times \left[\sum_{k=1}^n AF(w_i, c_k, pc_1) \right]$$

and n is the number of hazard potentials which, by themselves, could cause the material to be placed in hazard category (hc_j).

- c. If the material was placed in category (hc_j) as a result of the additive effects of various hazard potentials, any one of which by itself is insufficient to cause the material to be placed in the category, then

$$\text{Fine} = M \times (\text{Base Rate of Penalty}) \times \frac{\left[\sum_{k=1}^n \text{AF}(w_i, c_k, pc_1) \right]}{n}$$

where n is the number of hazardous potentials which, when considered together, caused the material to be placed in category (hc_j).

Final rates of penalty for each hazardous material have been computed and are included in Appendix N.

SAMPLE CALCULATIONS

Sample calculations for three hazardous materials in three water body types are performed below.

Case 1 - Acetaldehyde in a lake

Material: acetaldehyde

Water body type: lake

Hazard category: C

Hazard potential which caused it to be placed in Category C: damage to living resources

Physical/chemical characteristics:
non-persistent, floats, volatile, soluble (liquid)

Adjustment factor: 3

$$\text{Rate of penalty} = \frac{\$360}{1000 \text{ gal}} \times .3 = \frac{\$108}{1000 \text{ gal}}$$

$$= \$136/100 \text{ gal} \times .3 = \$41/100 \text{ gal}$$

Case 2 - Cadmium sulfate in a river

Material: cadmium sulfate

Water body type: river

Hazard category: A

Hazard potential which caused material
to be placed in Category A: bioaccumulation

Physical/chemical characteristics:
persistent, sinks, soluble

Adjustment factor: 0.8

$$\begin{aligned}\text{Rate of penalty} &= \frac{\$410}{10 \text{ kg}} \times .8 = \frac{\$328}{10 \text{ kg}} \\ &= \frac{\$190}{10 \text{ lbs}} \times .8 = \frac{\$152}{10 \text{ lbs}}\end{aligned}$$

Case 3 - Phenol in an estuary

Material: phenol

Water body type: estuary

Hazard category: B

Hazard potential which caused material
to be placed in Category B: tainting (bioaccumulation)

Physical/chemical characteristics:
non-persistent, mixer (90% solution)*

Adjustment factor: .45**

$$\begin{aligned}\text{Rate of penalty} &= \frac{\$360}{100 \text{ l}} \times .45 = \frac{\$162}{100 \text{ l}} \\ &= \frac{\$136}{10 \text{ gal}} \times .45 = \frac{\$61}{10 \text{ gal}}\end{aligned}$$

*In computing the fine for the spillage of a 90% solution phenol the rate of penalty would be multiplied by 0.9 to account for the fact that pure phenol was not spilled.

**Since no adjustment factor was determined for non-persistent "bioaccumulative" materials, the adjustment factor of 0.45 based on aquatic toxicity was used because of its similarity of action to tainting.

VII. DOHM METHODOLOGY

BRIEF

The methodology developed within this portion of the study is an extension of an approach formulated by the Division of Oil and Hazardous Materials (DOHM), U. S. Environmental Protection Agency, for assessing the impacts of hazardous material spills in streams. This approach uses a simplified plug flow model to assess the quantity of a hazardous material (harmful quantity) which when spilled is capable of inflicting substantial harm to key aquatic organisms in a stream. The wide applicability of Section 311 requires that harmful quantities for other types of water bodies such as lakes, estuaries, and coastal zones be determined. To this end, the basic DOHM plug flow model has been extended and modified whenever possible to meet these requirements.

In the following discussion, each of the four basic water body types (streams, lakes, estuaries, and coastal zones) is considered separately. The aim is that of defining a critical volume, the contamination of which results in substantial harm. For the stream and estuary categories, statistical samples of U. S. water bodies were analyzed to determine this critical volume. Simplified plug flow models of these water bodies were then used to determine harmful quantities based on the amount of hazardous substance required to bring the critical volume to the critical concentration level. Harmful quantities for lakes and coastal zones were extrapolated from the stream and estuary harmful quantities, respectively.

Naturally, the use of a plug flow model to characterize such hydrodynamically complex water bodies as streams and estuaries requires a number of simplifying assumptions. That these simplifying assumptions detract from the precision of the methodology is, of course, recognized by the authors and an attempt to compensate for the discrepancies that arise between the models and the natural environment has been made in the form of an adjustment factor.

Determination of the rate of penalty is independent of that of the harmful quantity in the DOHM Methodology. For this approach, the rate of penalty is equated to the cost which would have been incurred by the discharger had he instituted measures to prevent the spill.

Separate "costs of prevention" have been determined for both stationary and mobile sources. The latter includes transportation by rail and barge. Data from sources in the trucking industry indicates that greater than 95 percent of spills occur at

transfer sites and, therefore, are largely stationary source occurrences.¹ In order to facilitate the development of cost of prevention projections, a prevention technique was selected for each potential source and cost data developed for this technique. The technique's effectiveness in preventing the occurrence of spills was then analyzed in order to develop an estimate of the quantity of material prevented from being spilled. The base level cost of prevention was determined by taking the ratio of the cost of prevention to the quantity of material prevented from being spilled.

A method is presented for employing the cost of prevention to derive the rate of penalty. The base level cost of prevention can be utilized directly as the penalty rate or an adjustment factor can be utilized to vary the cost of prevention as a function of chemical characteristics of each substance. This latter variation recognizes that differences exist in potential levels of harm which can be inflicted by different substances and that higher levels of prevention (more costly) should be justified to reduce the possibility of spills of more hazardous substances.

Figure VII-1 represents the flow diagram of the procedure required by the DOHM Methodology to develop a harmful quantity and rate of penalty for any substance. The following sections provide detailed explanations of the steps identified in the diagram.

HARMFUL QUANTITY DETERMINATION

Stream Model

The DOHM² stream model assumes that a hazardous material is spilled into a stream over a finite period of time, that it mixes instantaneously to a uniform concentration equal to the critical concentration, and that the plug formed by the spilled material proceeds downstream without being subjected to further dissipation by hydrodynamic forces. Thus, for a given critical concentration, the time of exposure at any point in the stream is a function of the spill size and the flow rate of the stream. Mathematically, this can be written as

$$T = KM/CQ$$

(VII-1)

¹U. S. Department of Transportation, Office of Hazardous Materials. "Reports of Spills of Hazardous Substances: Computer File," as abstracted by Mr. Robert Reese, National Tank Truck Carriers, Washington, DC.

²U. S. Environmental Protection Agency, Division of Oil & Hazardous Materials. "The DOHM Approaches," Annex to RFP WA74-R064, distributed at Bidder's Conference, November 6, 1973.

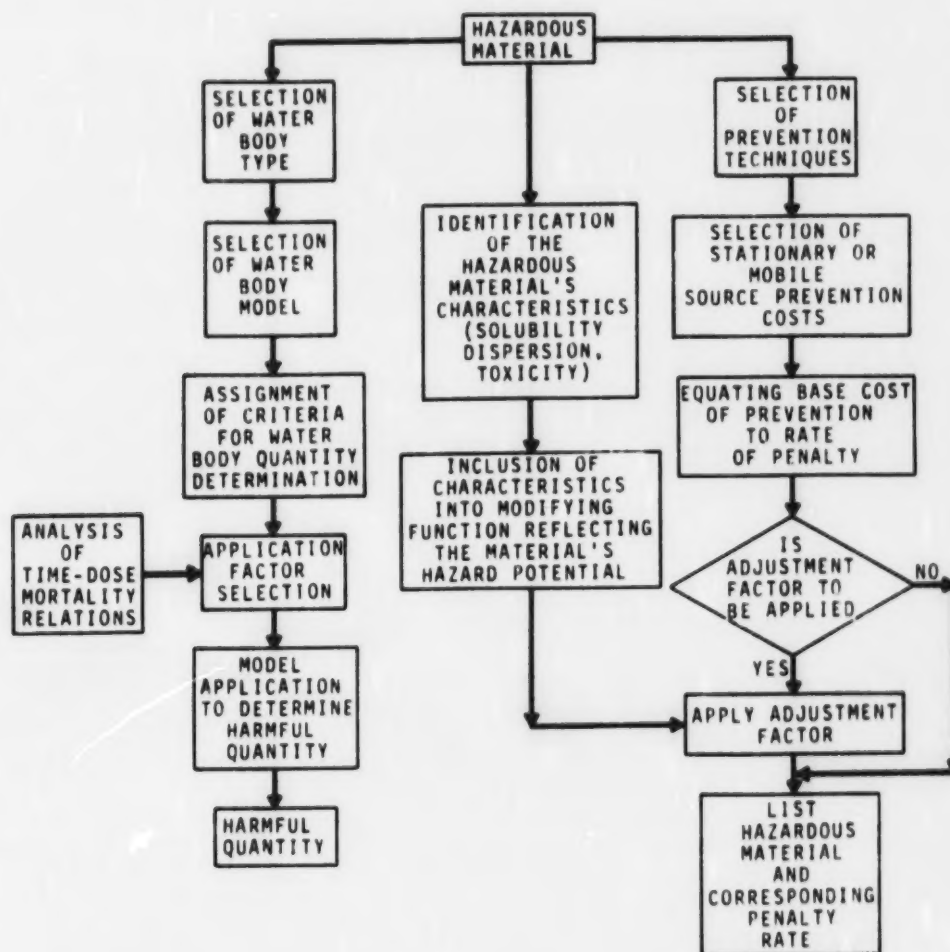


FIGURE VII-1. FLOW DIAGRAM FOR DOHM - COST OF PREVENTION METHODOLOGY

where

T = time for the plug to pass a point in the stream (hrs),

M = mass of pollutant spilled (kg),

Q = stream flow rate (m^3/sec),

C = critical concentration (mg/l), and

K = constant ($\text{hr-mg-m}^3/\text{sec-kg-l}$)

This expression may be rewritten as:

$$M = TCQ/K \quad (\text{VII-2})$$

The above expression can be used to determine the harmful quantity ($M = HQ$) when the following operations are performed.

- A functional relationship between T and C must be derived relating the critical concentration (C) to a time of exposure (T) over which the receptor must be exposed to the plug for substantial harm to occur (assuming a stationary receptor, this implies that T is also equivalent to the time of passage for the plug); and
- The flow rate (Q) must be defined at a level sufficient to imply that harm to aquatic organisms in a stream of that flow or greater is considered substantial to the environment.

Since in this study the critical concentration has been taken to be the 96 hr LC₅₀ for a median sensitive receptor, the only meaningful time of passage of the plug (T) is automatically fixed at 96 hours, since a stationary receptor will be exposed for 96 hours while the plume passes by -- leading edge to trailing edge. In reality, the time of passage of a plug of spilled hazardous material can vary substantially; however, within the range of reasonable spill duration there is a time of passage which, when combined with its associated critical concentration, yields a minimum harmful quantity in that range. This minimum harmful quantity (the smallest quantity required to produce substantial harm) is not necessarily the one derived from the 96 hour plug. In the next section an application factor is derived which can be used to determine this minimum harmful quantity. It is important to note that even smaller harmful quantities may be derived with times of passage outside the range of interest. Therefore, the minimum referred to here is a minimum only in the range of interest.

Derivation of the stream flow rate (Q), representing substantial harm to the environment is done statistically in the section entitled "Stream Quantity Determination."

Application Factor

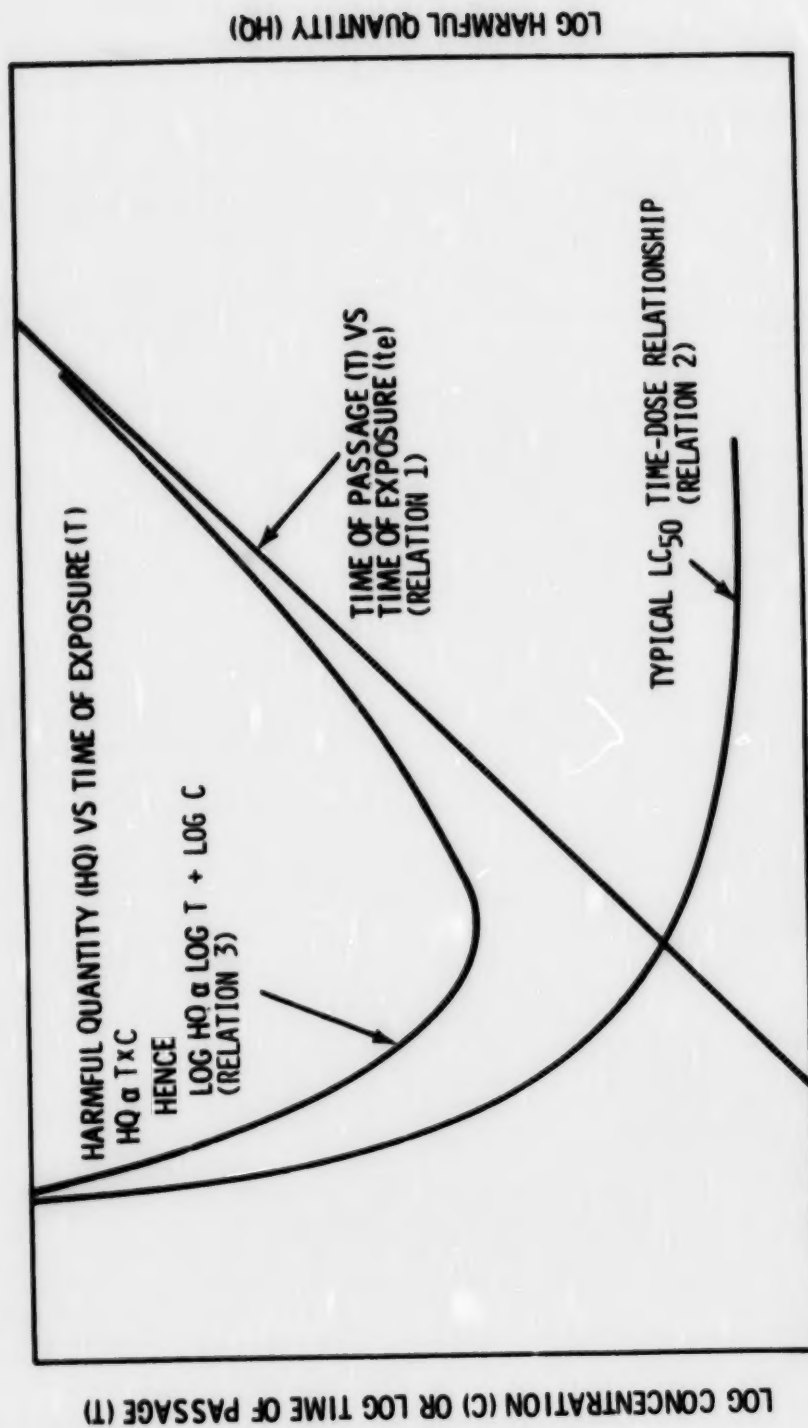
It is obvious that when 96 hour LC_{50} data are employed in the plug flow model described above, substantial harm can only be defined as exposure of the aquatic population to the concentration level equivalent to the 96 hour LC_{50} for a period of 96 hours or more. Intuitively, however, one can envision a situation requiring less time to pass could lead to equivalent levels of damage. The situation is illustrated in Figure VII-2. Time of passage is the same as the time of exposure (relation 1). Critical concentration is related to time of exposure in an inverse manner (relation 2). Since harmful quantity is proportional to the product of these factors, the harmful quantity curve is equivalent to the sum of the other curves when plotted on a log-log grid (relation 3). This forms a characteristic minimum. Hence, given a particular time-dose mortality relation, there is a unique time of passage for the contaminated plug which when employed in the plug flow model will result in the smallest harmful quantity, all other factors remaining equal. Similarly, within the time range of direct interest, there is a unique time associated with the smallest harmful quantity that can be derived in that time range. These two quantities will not necessarily coincide. Therefore, before the minimum is located, it is first necessary to define the time of passage range of direct interest to this study. That is, what time of passage range is representative of most hazardous material spills.

Ideally, the appropriate time range would be selected from historical spill data. Unfortunately, the data base for such an analysis is nonexistent at this time. Only recently have efforts been made to routinely report spills, and reports rarely include an estimation of the time of travel for the plug to pass a stationary point. This omission reflects the difficulty of making such an observation without sophisticated analytical equipment available, and an understandable tendency to yield higher priority to on-scene safety precautions and damage mitigation activities.

In the absence of historical data on time of passage for the contaminated plume, an attempt has been made to correlate available data on duration of fish kills and subsequently estimate the time of passage based on the apparent time of exposure of the receptor. The rationale for such a correlation has been discussed previously in Chapter III in the section dealing with selection of critical concentrations.

Fish kill duration data reported for the years 1960-1972 have been reviewed and are plotted in accumulative probability form

TIME-DOSE MORTALITY RELATIONSHIP



LOG EXPOSURE TIME (t_e)
 FIGURE VII-2. RELATIONSHIPS BETWEEN HARMFUL QUANTITY, TIME
 OF PASSAGE AND CRITICAL CONCENTRATION

in Figure VII-3.³⁻¹² (It should be noted that the two curves in this figure are merely reciprocals of each other.) Based on the availability of toxicological data, 96 hours has been defined as the upper limit of interest for acute spills. Therefore, it is necessary only to select a lower limit. From Figure VII-3 it is apparent that 95 percent of all fish kills have a duration of six hours or more. By implication then, most contaminant plugs resulting from spills require at least six hours to pass a point. This does not imply that the spills themselves occur over a period of six hours, but that after initial mixing, contaminant plugs typically require more than six hours to pass a stationary point. Consequently, the time of passage range of interest is 6-96 hours.

With the range of interest (6-96 hours) thus defined, it is necessary to determine where, in that range, the point associated with minimum harmful quantity occurs. In Appendix L, it is shown that for most hazardous substances the minimum for the entire relation $HQ = QCT/K$ occurs at a time of passage less than six hours. Thus, the smallest harmful quantity in the range of interest (6-96 hours) will occur at the six hour point; i.e., if the minimum harmful quantity occurs to the left of the six hour point in Figure VII-2, no point to the right of the six hour level will have a lower value than that at six hours.

³"Pollution-Caused Fish Kills in 1960," U. S. Department of Health, Education, and Welfare, Public Health Service, 1960.

⁴"Pollution-Caused Fish Kills January-September 1961," U. S. Department of Health, Education, and Welfare, Public Health Service, Washington, DC, November 1961.

⁵"Pollution-Caused Fish Kills in 1963," U. S. Department of Health, Education, and Welfare, Public Health Service, Washington, DC, 1963.

⁶"Pollution-Caused Fish Kills in 1964," U. S. Department of Health, Education, and Welfare, Public Health Service, Washington, DC, 1964.

⁷"Pollution-Caused Fish Kills in 1965," U. S. Department of the Interior, Federal Water Pollution Control Administration, Washington, DC, 1965.

⁸"Fish Kills by Pollution in 1966," U. S. Department of the Interior, Federal Water Pollution Control Administration, Washington, DC, 1966.

⁹"Pollution-Caused Fish Kills in 1967," U. S. Department of the Interior, Federal Water Pollution Control Administration, Washington, DC, 1967.

¹⁰"Pollution-Caused Fish Kills in 1968," U. S. Department of the Interior, Federal Water Pollution Control Administration, Washington, DC, 1968.

¹¹"1969 Fish Kills Caused by Pollution," Federal Water Quality Administration, USGPO, Washington, DC, 1970.

¹²"Fish Kills Caused by Pollution in 1970," U. S. Environmental Protection Agency, USGPO, Washington, DC, 1972.

ACCUMULATED PERCENTAGE OF REPORTED FISH KILLS VERSUS DURATION

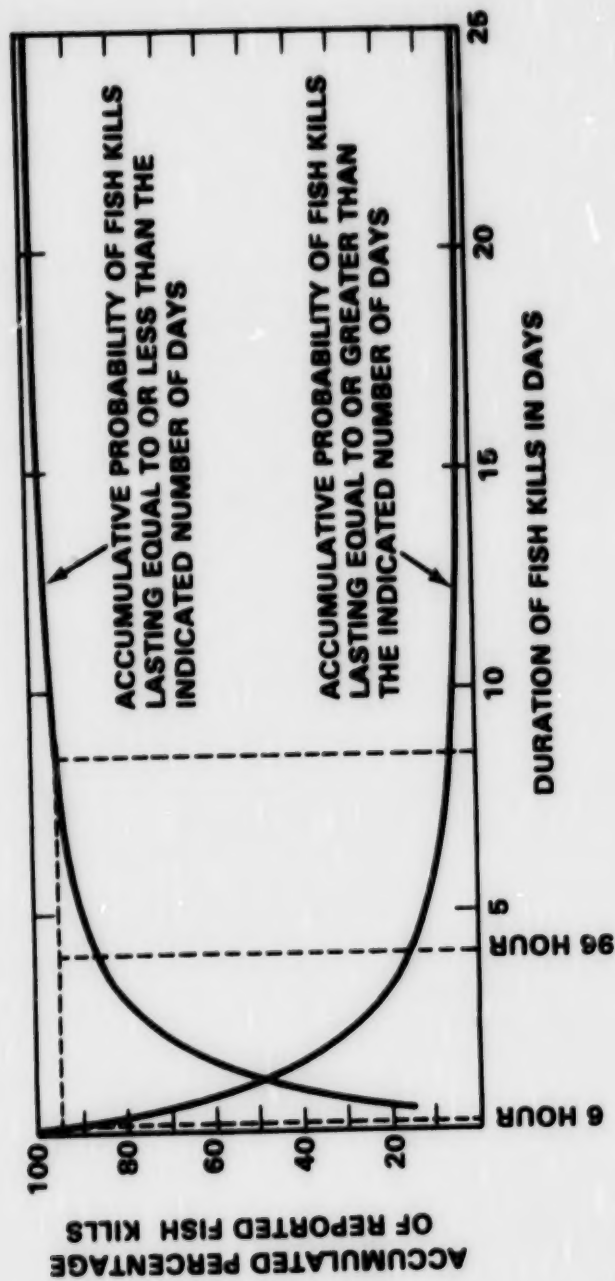


FIGURE VII-3. ACCUMULATED PERCENTAGE OF REPORTED FISH KILLS VERSUS DURATION³⁻¹²

As shown in Appendix L, the latter condition does indeed prevail for most hazardous substances. The controlling variable in determining the location of the minimum point for the overall relation is the value of the incipient time threshold, the asymptote approached by time-dose mortality curves as the minimum time required to kill fish when toxic materials are present at high concentrations. As long as this threshold is less than six hours, the time associated with a minimum harmful quantity will be less than six hours. In general, the incipient time threshold has been found to be less than one hour for all hazardous substances for which time-dose mortality information has been reviewed. Consequently, no materials have been identified for which the absolute minimum harmful quantity would occur at a time (T) greater than six hours and, hence, usage of a six hour time of passage will represent the smallest harmful quantity in this time range of interest. While smaller harmful quantities would result from use of times less than 6 hours, these are rejected on the basis that most spills are simply not concentrated into such short, intense plugs.

As a result of this finding, the nature of the required application factor can be clearly defined. It must be an appropriately selected quantity to 1) reduce the time of passage from 96 hours to six hours, and 2) convert the 96 hour LC₅₀ to a critical concentration representative of six hour exposures. The first task is simple in that one needs only to divide by 16 (96 hr/6 hr). The second is more difficult.

Ideally, one would avoid use of any application factor and merely operate the model employing a six hour time of passage and the six hour LC₅₀ for each hazardous substance. Unfortunately, six hour LC₅₀ information is nonexistent for most materials. Thus, an application factor is necessitated which represents a quantification of the average relation between the 96 and 6 hour LC₅₀'s. This can be accomplished only through further analysis of time-dose mortality relations such as those illustrated in Figure VII-4.

Available time-dose mortality relations were gathered and reviewed to determine the average relation of the 96 hour LC₅₀ to the six hour LC₅₀. (This data is rather sparse and is not routinely gathered in the United States. Hence, Canadian and European sources provided the bulk of the data analyzed.) The ratios of the 96 hour to the six hour LC₅₀ for designated hazardous substances and common aquatic species are presented in Table VII-1. It is evident that no single value characterizes a chemical or species. Values fall anywhere in the range 0.006-1.0 as a function of both the species and the chemical. In the absense of a strong rationale for selecting any single value, it is recommended that the mean value, 0.5, be employed as representative. It can be

REPRESENTATIVE TIME-MORTALITY CURVES

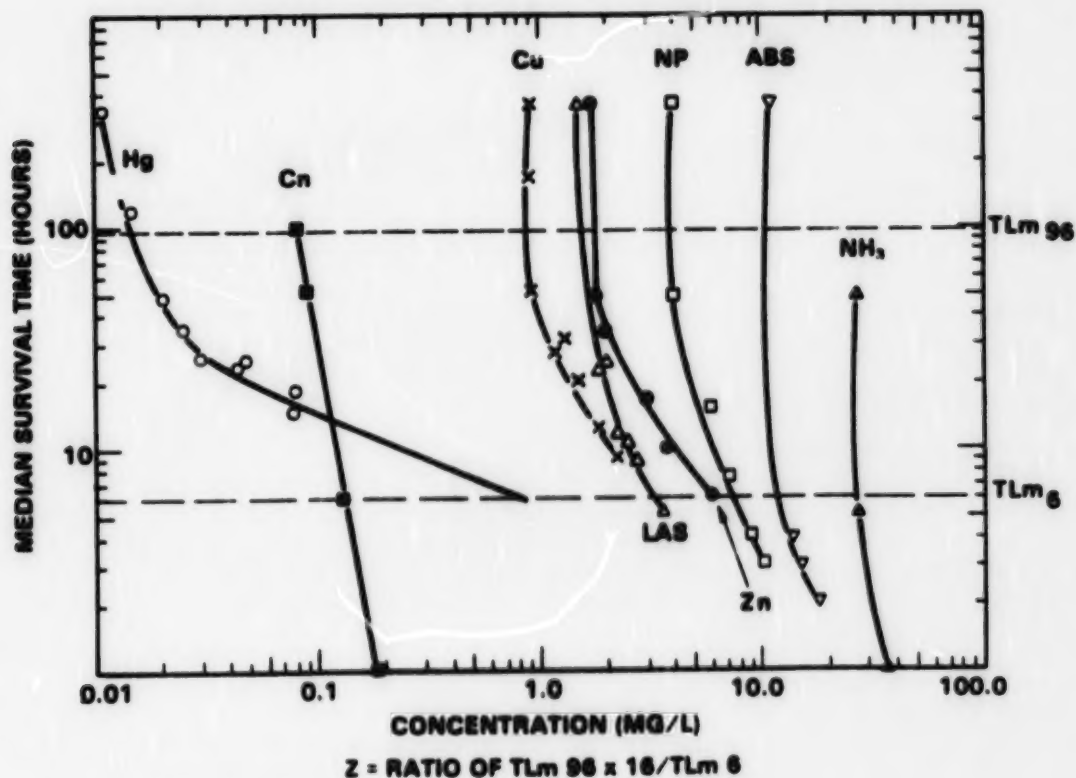


FIGURE VII-4. REPRESENTATIVE TIME-DOSE MORTALITY CURVES^{13,14,15}

¹³Calamori, D. and R. Marchetti. "The Toxicity of Mixtures and Surfactants to Rainbow Trout (*Salmo gairdneri* Rich.)," Water Research, Vol. 7, 1973.

¹⁴Herbert, D. W. M. and J. C. Merkins. "The Toxicity of Potassium Cyanide to Trout," J. Exp. Biol., Vol. 29, pp. 632-649, 1952.

¹⁵Lloyd, R. and D. H. M. Jordan. "Some Factors Affecting the Resistance of Rainbow Trout (*Salmo gairdneri*) to Acid Waters," J. Air & Water Pollution, Vol. 8, pp. 292-403, 1964.

TABLE VII-1

THE RATIO OF 96 TO 6 HOUR LC₅₀ FOR COMMON SPECIES
EXPOSED TO DESIGNATED HAZARDOUS SUBSTANCES

<u>Species</u>	<u>Substance</u>	<u>Ratio = $\frac{96 \text{ Hr LC}_{50}}{6 \text{ Hr LC}_{50}}$</u>	<u>Reference</u>
Rainbow Trout	NH ₄ CL	1.00	2, 23, 27, 29
	Fluoride	1.00	17
	NH ₃	0.96	2, 27, 32
	ABS	0.85	13
	Phenol	0.74	22, 28
	CN	0.60	14, 31
	Cl ₂	0.39	34
	ZnSO ₄	0.30	2, 27, 9
	Zn	0.28	2, 27, 9
	Cu	0.25	13
	DDT	0.01	15
	Hg	0.006	13
Salmon	Phosphorus	0.29	19
	Cu	0.21	24, 25
	Zn	0.13	2
	Cu	0.06	2
	Cu	0.06	24, 25
	DDT	0.01	20
	Phosphorus	0.006	19
Cod	ABS	0.57	18
	Phosphorus	0.11	19
	Phosphorus	0.006	19
Bluegill	Benzene	1	33
	Aniline	0.06	33
Common Perch	NH ₃	0.34	30
	Phenol	0.19	30
	Cn	0.05	30
Crab	Zn	0.12	21
	Hg	0.02	21
	Cu	0.006	21
Shrimp	Cu	0.08	21
	Hg	0.006	21
Harlequin Fish	KCN	0.83	16
	Na ₂ S	0.59	16
	Phenol	0.34	16
	DDT	0.02	15

noted that this value is also the median value of those reported for rainbow trout. Insufficient data on remaining species prohibits a further analysis for median values. There is also some basis in theory for selecting the mean or median value. Wuhrmann³⁰ notes that both the incipient lethal concentration (the asymptote with essentially infinite exposure) and the slope of the time-dose mortality relation are measures of the relative sensitivity of a species. Since it has previously been determined that toxicity data should be that for a median receptor, it is reasonable to assume that a median value for the 96 hour to 6 hour LC₅₀ ratio representative of a median average slope on the time-dose mortality curve is the best selection.

Combining the quantities required to modify the plug flow equation for deriving a harmful quantity, one obtains an application factor (S) with a value of

1) conversion of T from 96 to 6 - factor 1/16

2) conversion of C₉₆ to C₆ - factor 2

$$S = (1/16) \times (2) = 0.125$$

Therefore, an application factor of 0.125 is required to transform the plug flow model (using 96 hr LC₅₀ values) into a useful formulation for deriving harmful quantities for acute hazardous material spills. The DOHM model now requires only a representative flow rate to make it operative.

Stream Quantity Determination

Using equation VII-2 for any given stream with a known flow rate (Q), it is possible to compute the quantity of hazardous material (HQ) which would be required to form a plug of duration (T) and concentration (C). Both C and T have been defined. Thus, in order to obtain a harmful quantity, one need only define the stream size, represented by its flow rate (Q).

Ideally, a harmful quantity could be assigned to each and every stream and river reach in the United States on the basis of its average median flow rate. This would result in a rather voluminous set of site specific harmful quantities. Aside from the tremendous effort that would be required to determine these harmful quantities, such a system would most certainly present an awesome administrative burden to the regulatory agency and operators of mobile sources who would be required to identify receiving waters and their flow rate in order to know the nature of the reporting requirements.

³⁰Wuhrmann, K. "Concerning Some Principles of the Toxicology of Fish," J. Fish. Res. Bd. Can., Translation Series No. 243, August 1959.

Recognizing these shortcomings, a simplified approach was utilized to determine the representative stream flow for the DOHM plug flow model. This approach is detailed in Appendix J. In brief, the continental United States is divided into twenty-four drainage basins, for which the daily runoff from each is determined and characterized as a percentage of the total daily runoff from the continental United States. Each basin is then classified into one of six categories on the bases of annual runoff (e.g., 0-5 inches of runoff, 5-10, 10-20) and each category is assigned a value equivalent to the total percent of United States flow which originates in the basins of each category. These values are subsequently used as weighting factors in the final determination of the representative flow for the DOHM model.

Representative basins for each of the six categories were then selected for detailed analysis focused on determining the fraction of the total volume of water flowing in the basin (at the median flow rate) at various discharge rates (Q). The manner in which the median was calculated is presented in Appendix J. By ranking the discharges and their associated volumes for each basin from high to low, it is possible to obtain an accumulative percentage of total volume versus discharge rate.

When the above operation has been performed for the representative river basins, a weighted average (incorporating the previously derived weighting factors) can be utilized to obtain a representative stream discharge rate (Q) for the entire United States. Mathematically the preceding takes the following form:

$$Q = W_1X_1 + W_2X_2 + \dots + W_iX_a$$

where Q = representative United States discharge value to be applied in the DOHM model

W_i = fractional weighting factor, based upon a drainage basin's average annual runoff category

X_i = stream flow values representing a particular accumulative volume percentage of the flow in a river basin for each runoff category.

This analysis was performed on the selected river basins listed in Appendix J. The results of this analysis are presented in Figure VII-5 which depicts the percent of total flow in the United States which is flowing at or above a particular discharge value on a median flow basis.

The flow rate at which 95 percent of the volume of water is represented by streams of equal or greater discharge has been chosen as the quantity of water for the DOHM plug flow model. This value is equivalent to 1 m³/sec (36 cfs). Admittedly, the

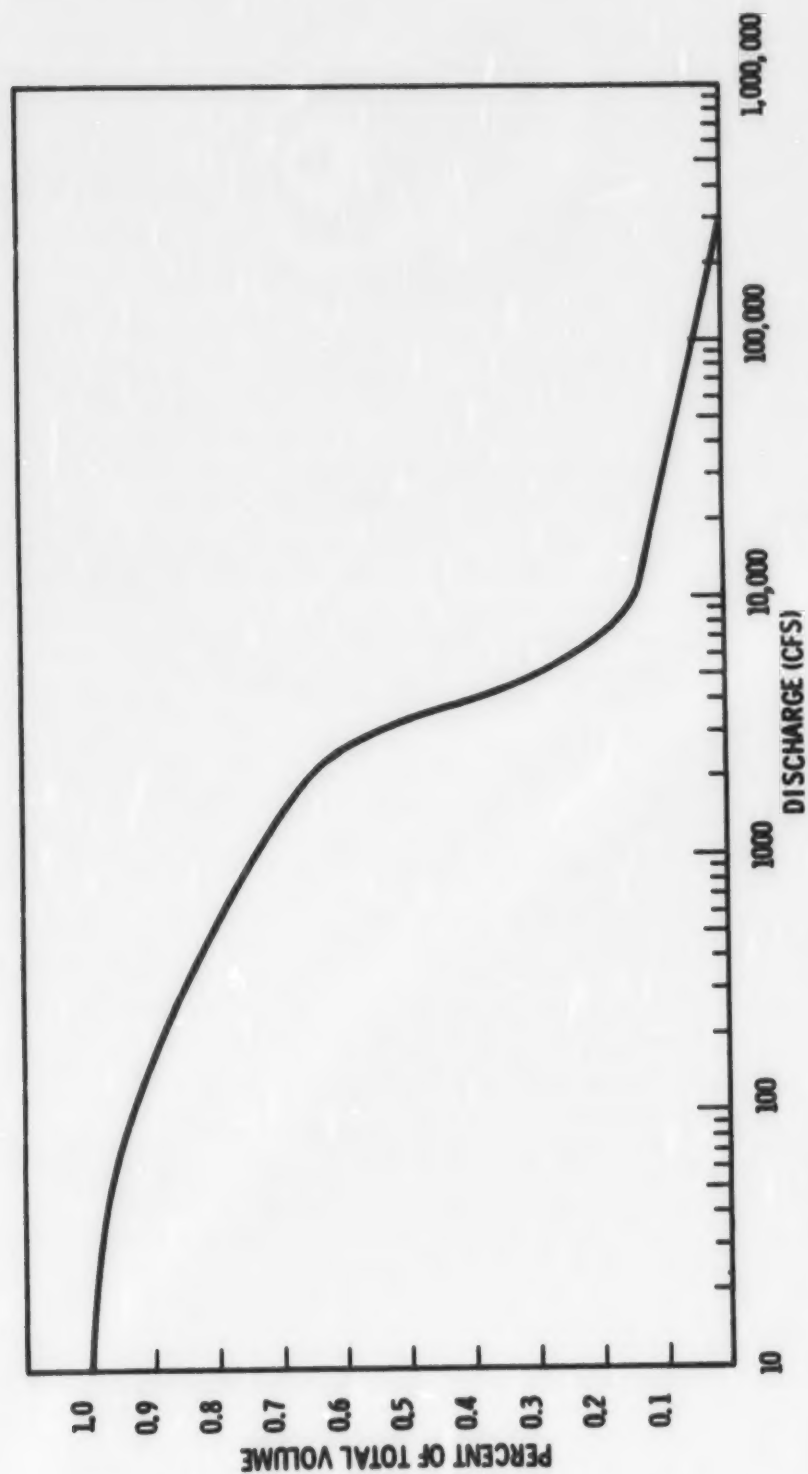


FIGURE VII-5. PERCENT OF TOTAL FLOW CONTAINED IN STREAMS OF THE STATED MEDIAN FLOW RATE OR GREATER

95 percent quantity selected here is somewhat arbitrary and could be replaced with any other cumulative fraction. The important point is not the absolute value selected so much as the realization that 100 percent is an infeasible level. Data are presented here to allow use of any other percentage should a strong rationale be developed to replace 95 percent.

Lake Model

The lack of sufficient data on lakes of the United States and their characteristics (size, shape, trophic state, overturn rate, flushing rate) has limited the available approaches for determining a representative lake quantity for the DOHM Methodology. Ideally, one would develop a statistical profile of the percent of total lakes or total lake waters (volume basis) in the U. S. represented by lakes of a given size or greater. If lake volume were used, the Great Lakes and several other large lakes such as Lake Tahoe would dominate the percentages. If either approach were taken, a detailed listing of lakes in the United States would be required. Such a compendium is not presently available and what data bases exist, are often biased to lakes with high present recreational values. For these reasons, a statistical approach was discarded.

A second tact was taken. It was noted that many impoundments or lakes are integral parts of a river system. As such, there is a continual exchange of river and lake waters. Since it is these lakes that are often threatened by spills, it is not unreasonable to employ them as representative of impounded waters. Following this line of reasoning, lake and river waters were classified jointly as freshwaters and given identical harmful quantities. Since the application factor converts the plug flow model to a 6 hour basis, this constitutes use of

$$\begin{array}{ccccccc} 36 \text{ cfs} & \times & 6 \text{ hrs} & \times & 3600 \text{ sec/hr} & \times & .0283 \text{ ft}^3/\text{m}^3 \\ (Q) & & (T \times S) & & (K) & & (K) \\ 21,600 \text{ m}^3 & & (17.5 \text{ acre-feet}) & & & & \end{array}$$

as the critical volume for lake waters. This implies that statistically important lakes are those which contain 21,600 m³ of water or more.

Estuarine Model

Section 311 specifies that a harmful quantity must be established for each hazardous material for all navigable waterways of the United States. Estuaries are some of the most heavily used transportation arteries in the world and consequently are very susceptible to spills of hazardous materials. Generalization of a plug flow model to an estuary is much more difficult than to

a river or stream. The estuary has several different dimensions to consider in comparison to a stream or river. Tides cause oscillatory motion of the water within the estuary, and the strength of the tide dictates the turbulence (or lack thereof) which will occur. The salinity difference between the ocean waters and the fresh waters results in stratification and internal (and opposing) currents developed between the fresh and salt water layers. Many estuaries, due to their size, are influenced by the earth's rotation and salinity variations within the estuary can arise due to the Coriolis force. Furthermore, estuaries are influenced by the volume of freshwater inflow occurring at any given time as well as by periodic changes in physical characteristics. All these factors influence the flushing and diluting action of the estuary and therefore assist or hinder the dispersion of a contaminant in the waterway.

Several definitions of estuaries exist. The working definition which will be utilized as a guide in the development of this methodology is: "a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage."¹⁶ Furthermore, the estuary is defined as being bounded at the head by the most upstream point of measurable quantities of ocean-derived salt and at the mouth by the farthest continuous point of land extending into the ocean.¹⁶ Due to an estuary's dynamic condition, the head end is not stationary. Depending upon the strength of the tide and the corresponding river flow, the estuary's head location may significantly vary.

Estuaries can be subdivided into several general classifications. The most prevalent classes include the stratified, the partially mixed, and the fully mixed estuary. Each type has distinct density, stratification, and circulation pattern characteristics. Furthermore, due to changing hydrologic and physical characteristics, few estuaries can be continuously classified as being only one of the preceding types. The classification an estuary assumes depends primarily upon the tributary inflows, tidal flow, width, and depth.¹⁷ Considering all other parameters equal, an estuary tends to shift from a highly stratified to a partially mixed, and then to a vertically homogeneous estuary with

- 1) Decreasing river flow,
- 2) Decreasing tidal velocities,

¹⁶Pritchard, D. W. "Dispersion and Flushing of Pollutants in Estuaries," ASCE, Hydraulics Division, pp. 115-124, January 1969.

¹⁷Pritchard, D. W. "Estuarine Circulation Patterns," ASCE, Hydraulics Division, pp. 717-1 - 717-11, June 1955.

3) Decreasing width, and

4) Decreasing depth.³⁸

Many estuaries, as typified by the estuaries of the Pacific Northwest, fluctuate through the complete cycle of estuary classifications during the course of a calendar year.

Numerous investigators have observed a correlation between an estuary's condition (stratified, partially mixed, or fully mixed) and the ratio of the fresh water discharged during a half-tidal cycle (~ 12.4 hours) to the tidal prism (volume of water represented by the difference between the estuary's size at mean high and mean low water).³⁸⁻³⁹ Naturally, such fluctuations influence the dispersion of a contaminant within an estuary.

For a fuller appreciation of the complexity of estuarine systems versus river systems, the reader is referred to Appendix K where the three prominent classes of estuaries are discussed in more detail.

Of the three predominant estuarine classifications, investigators have found that the partially mixed estuarine system is by far the most prevalent.⁴⁰ This type of estuary can be conceptualized as a two flow system. The fresh water has a net seaward advance along the surface of the estuary and the salt water has a net landward movement along the bottom. Turbulence at the interface results in a local condition of partial mixing. In the case of a hazardous material spill into a partially mixed estuary, dilution water would be provided by 1) the fresh water tributary inflow, and 2) the ocean water flowing upstream during a flood tide. Hence, the contaminated area can be visualized as being flushed and dispersed by two streams of flow. This generality applies quite well for the completely mixed estuary and has increasingly less applicability as the estuary approaches the stratified state.

Several authors have indicated that a partially mixed estuary has a ratio of fresh water inflow (Q_f) to tidal prism (P) on the order of 0.1 - 0.5 ($0.1 \leq Q_f/P \leq 0.5$).³⁸⁻³⁹

³⁸Burt, W. V. and W. B. McAlister. "Recent Studies in the Hydrography of Oregon Estuaries, Research Briefs, Fish Commission of Oregon," Vol. 7, No. 1, pp. 14-27, July 1959.

³⁹Simmons, H. B. "Field Experience in Estuaries," Estuary and Coastline Hydrodynamics, McGraw-Hill Book Company, Inc., pp. 673-690, 1966.

⁴⁰Pritchard, D. W. "Observations of Circulation in Coastal Plain Estuaries," Estuaries, American Association for the Advancement of Science, pp. 37-51, 1967.

Choosing a ratio of $Q_t/P = 0.1$ for the model development will result in the inclusion of the majority of partially mixed and fully mixed estuaries. A flow ratio greater than 0.1 would result in improved dispersion of the contaminant. Hence, the use of 0.1 constitutes a conservative assumption. For the stratified estuaries ($Q_t/P \sim 1.0$) the dilution water available in comparison to a partially mixed estuary can be an order of magnitude larger, or can be essentially zero depending upon where the spilled material resides. Lighter materials ($SpG < 1$) will sink to the salt wedge where dilution is minimal and hence may lead to high concentrations over an extended time period.

Water Quantity Determination

To facilitate the estuarine analysis, the model estuary is defined as an elongated indentation in the coastline with a single river source of fresh water at the upper end and a free connection with sea at the lower end. A partially mixed system with a $Q_t/P = 0.1$ conceptualized as a system with two opposing streams of diluting water was utilized.

The model to be presented in the following pages represents a modification of Fischer's proposed model dealing with the continuous discharge of pollutants into an estuary.⁴¹ In addition to those already presented, the following assumptions have been made:

- Complete mixing of the hazardous material in the combined two stream flows (fresh tributary water and new ocean water), and
- Instantaneous mixing of the contaminant to a uniform concentration equivalent to the mean toxicity level.

The degree of mixing of the hazardous material will depend upon the extent of partial mixing of the estuary existing at the time of discharge. Instantaneous mixing of the contaminant to a uniform concentration will result in the formation of a plug. Again, the validity of this assumption is dependent upon the state of mixing existing within the estuary and actually may vary diurnally within any one estuary. This conceptualization leads to the illustration in Figure VII-6.

The streams (tributary and ocean flow) will result in the following concentration of spilled material (assuming the spill volume is negligible in comparison to the two stream flows):

⁴¹Fisher, H. B. "Affidavit Concerning Section 307," for the U. S. Environmental Protection Agency.

$$C = M / [(Q_t + RP/D) \times (T)]$$

(VII-3)⁴¹

where R = tidal exchange ratio--the ratio of new ocean water to total tidal flow moving past the location of the spill during a flood tide,

P = tidal prism upstream from the spill discharge point, (cubic feet)

D = duration of tidal cycle (24 hours and 50 minutes in seconds),

Q_t = tributary discharge, (cubic feet per second)

C = concentration of material on the combined streams flow (lbs/ft^3), set equivalent to critical concentration for the purposes of harmful quantity determination,

M = quantity of material spilled, (lbs)

T = time of the total plug formed to pass a point (leading edge to trailing edge), (seconds) and

RP/D = effective flow of new ocean water passing the discharge point (water not contained in previous tidal cycle) (cfs).

Since the estuarine system has been idealized as a stream with an effective discharge (Q), characterized by the summation of total inflows and outflow, the plug flow model can be extended

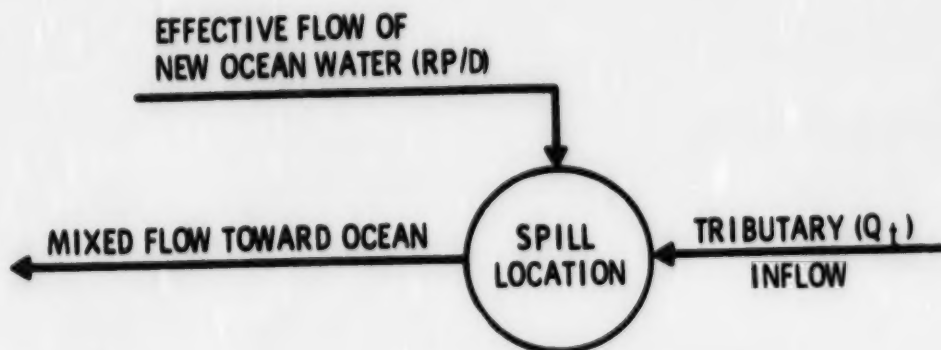


FIGURE VII-6. TWO DILUTION STREAM SYSTEM⁷

to this situation. As in the case of the stream, the hazardous material spilled will be idealized to spread out into a 96 hour plug of uniform concentration equivalent to the mean toxicity level for a median receptor. Naturally, such an idealized plug size may never occur in an estuary. Hence, the application factor discussed previously in the stream model section will be applied to the preceding formula to adjust the harmful quantity in order to reflect the possibility of higher concentration levels in a shorter length plug. Thus, equation (VII-3) can be rearranged to include the application factor in order to determine a harmful quantity level

$$HQ = (Qt + RP/D) (T) (C) (S) (K) \quad (VII-4)$$

where K = unit conversion constant

S = application factor

HQ = harmful quantity.

The preceding formula can be simplified by applying the law of conservation of mass to the salinity balance of the estuary obtaining

$$HQ = K \left(\frac{So}{So-Se} Qt \right) (T) (C) (S) \quad (VII-5)$$

A more detailed derivation of the above relation is given in Appendix K. Hence, to apply the preceding formula to an estuary one needs to know

So = average salinity of the ocean waters,

Se = average salinity of the water leaving the estuary,

Qt = tributary discharge, and

S = application factor

In the generalized case, the average salinity of the ocean waters can be assumed to be 34 ppt and the average salinity of the water leaving the estuary would be 31 ppt since Qt/P has been assumed to be equal to 0.1. The tributary inflow value was obtained in a fashion similar to the approach used to derive the discharge rate (Q) in the stream model. Data from the National Estuarine Pollution Study⁴² was analyzed to obtain a cumulative percentage of estuarine inflow versus the inflow rate (Qt). The results of this analysis are presented in Figure VII-7. As with the

⁴²"National Estuarine Pollution Study," a report to the 91st Congress by the Secretary of the Interior pursuant to Public Law 89-753, March 1970.

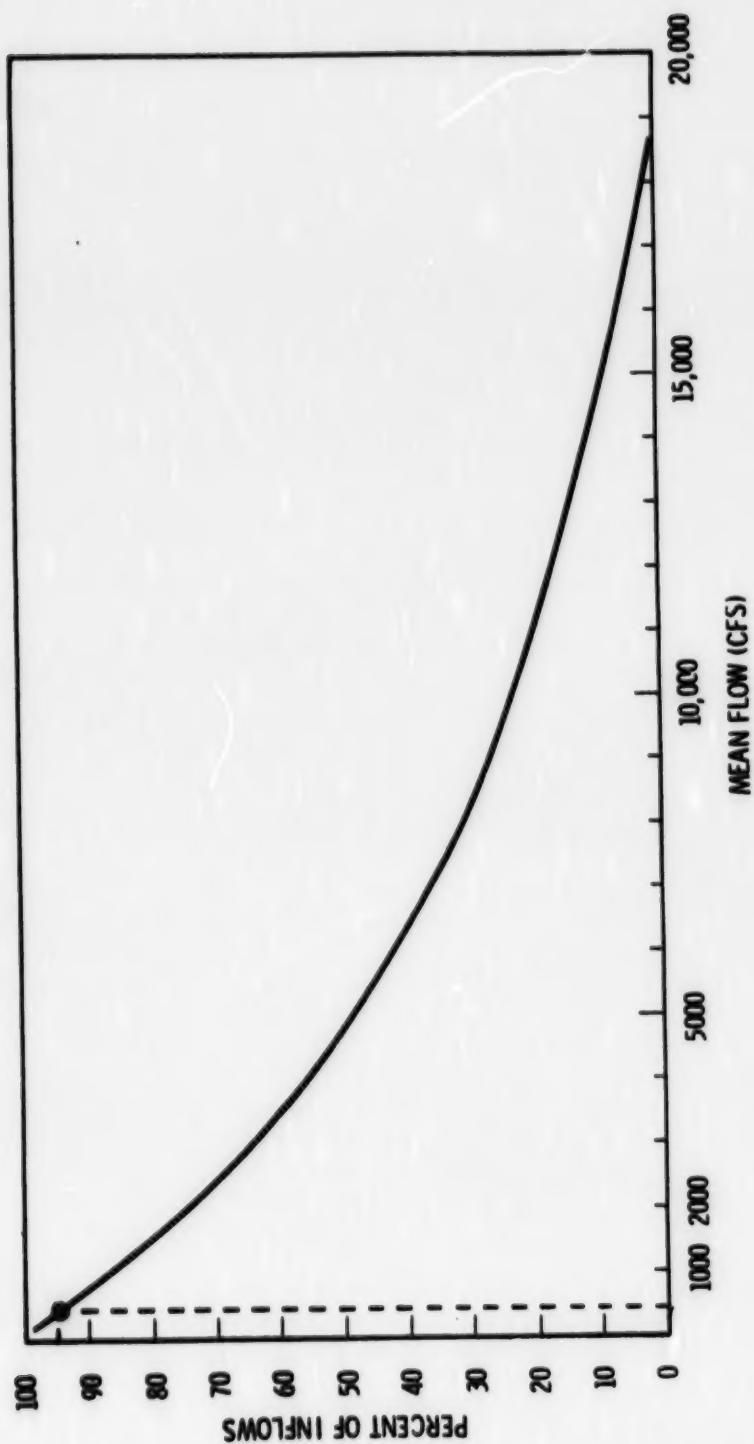


FIGURE VII-7. FRACTION OF TOTAL ESTUARINE INFLOWS (Q_t) DERIVED FROM STREAMS WITH THE STATED MEDIAN FLOW OR GREATER

stream model, the 95th percentile was selected as the threshold. The average flow corresponding to this 95 percent level was 11.33 cubic meters/second (400 cfs) which is approximately correlated with a median flow of 5.67 cubic meters/second (200 cfs). This median flow rate is used in equation VII-5 to compute harmful quantities for estuaries.

Ocean Model

Since the outer limit of the estuary has been defined as the furthest continuous point of land extending into the ocean, spills just outside the mouth of an estuary would be defined as occurring in the coastal zone. In such a situation, subject to localized hydrodynamics, the threat of significant harm occurring to the biota of the estuary could be substantial. Furthermore in many instances, operators of mobile sources would find it most difficult to determine if a coastal spill occurred within estuarine or coastal waters. Therefore for the DOHM approach, harmful quantities derived for a model estuary have been applied to the contiguous zone as well. Consequently, a single harmful quantity is designated for all marine waters just as a single harmful quantity is designated for all fresh waters. This is equivalent to employing a volume of ocean water of

$$6 \text{ hrs} \times 200 \text{ cfs} \times 10 \times 3600 \text{ sec/hr} \times .0283 \text{ m}^3/\text{ft}^3 = 1,370,000 \text{ m}^3$$

$$(TxS) \quad (Qt \times \frac{So}{So-Se}) \quad (K) \quad (K)$$

(1120 acre-feet)

Harmful Quantity Calculation

With the parameters in equations VII-2 and VII-5 specified, the harmful quantity for each water body can be determined. The appropriate equations for each of the water bodies are shown in Table VII-2.

The stream harmful quantity equation is based upon the flow rate at which 95 percent of the volume of water is represented by streams of equal or greater discharge. A harmful quantity has been calculated for each substance within each water body and the values have been tabulated in Appendix N. Example harmful quantity calculations are presented in Table VII-3.

Locational Factor

Greater resolution could be obtained if the plug flow model were modified to employ the actual flow of the receiving water as well as real hydrodynamic characteristics. This would be applicable

TABLE VII-2

HARMFUL QUANTITY EQUATIONS

<u>Water Body</u>	<u>Applicable Harmful Quantity Equation</u>	<u>(Kilograms)</u>	<u>(Pounds)</u>
Stream	(Eq VII-2) HQ =	43.9 CC	96.8 LC ₅₀ ₉₆
Estuary	(Eq VII-5) HQ =	2773 CC	6113 LC ₅₀ ₉₆
Lake	(Eq VII-2) HQ =	43.9 CC	96.8 LC ₅₀ ₉₆
Ocean	(Eq VII-5) HQ =	2773 CC	6113 LC ₅₀ ₉₆

CC = critical concentration

TABLE VII-3

EXAMPLE HARMFUL QUANTITY CALCULATIONS

<u>Chemical</u>	<u>Freshwater Critical Concentration (mg/l)</u>	<u>Saltwater Critical Concentrations (mg/l)</u>
Acetaldehyde	53.0	70.0
Phenol	12.0	23.5
Cadmium sulfate	5.6	15.1

I) Stream and lake

- i) Acetaldehyde: $HQ = (43.9) \times (53) = 2327 \text{ kg (5126 lbs)}$
- ii) Phenol: $HQ = (43.9) \times (12) = 527 \text{ kg (1161 lbs)}$
- iii) Cadmium sulfate: $HQ = (5.6) \times (70) = 392 \text{ kg (864 lbs)}$

II) Estuary and ocean

- i) Acetaldehyde: $HQ = (2773) \times (70) = 194,110 \text{ kg (428,000 lbs)}$
- ii) Phenol: $HQ = (2773) \times (23.5) = 65,165 \text{ kg (144,000 lbs)}$
- iii) Cadmium sulfate: $HQ = (2773) \times (15.1) = 41,873 \text{ kg (92,000 lbs)}$

only to stationary sources where the receiving waters likely to accept a discharge could be evaluated prior to an actual spill. Such a variation would tailor harmful quantities to individual geographical locations. The approach would not apply to mobile sources, since reporting requirements would necessitate the operator to estimate the flow or any receiving waters into which a spill might have occurred. The obvious risk of criminal penalty would influence toward conservative estimates. This could be avoided by setting a single standard guideline for mobile sources. This modification has not been made in the trial calculations presented here.

A second modification which can be made is the designation of a separate harmful quantity for spills from barges based on the realization that barge traffic is unique to streams with larger flow rates. An accumulative flow determination has been made for rivers and streams carrying barge traffic in the same manner as described previously for the stream and estuary models. Assuming a 95 percent threshold as before, a flow rate of 172 m³/sec (6190 cfs) should be employed in the harmful quantity formulation. This would result in harmful quantities for barge spills approximately 172 times as large as those for spills into streams in general. This modification has not been employed for the calculations presented here.

RATE OF PENALTY

Cost of Prevention

Two general concepts are expressed within Section 311 concerning the spillage of hazardous materials. Subsection (b)(1) states that "...no discharge of oil or hazardous material shall be permitted in navigable waters of the United States...". Furthermore, the law recognizes that spills or discharges do occur and in subsection (b)(2)(B)(iii) states that "...discharge(s) (of) any hazardous substance determined not removable...shall be liable...for either one or the other of the following penalties...".

The apparent goal of Section 311 as it applies to non-removable hazardous substances is the elimination of their discharge through the use of monetary penalties which act as an inducement to the spiller to initiate positive actions to prevent spillage. In order for these penalties to be effective deterrents, the potential penalties assessed an individual or corporation must be sufficiently high to provide economic incentive to reduce or eliminate spillage. For the economically rational firm, the incentive to prevent spillage will occur when the annual level of assessed fines exceeds the annual cost of prevention equipment (assuming externalities such as public relations and image have a minor influence upon the decision). Hence, the individuals or organizations influenced by Section 311 will have to review their spill history records to assess the risk of penalties that they may incur and weigh this additional cost of operation versus the cost of installing various prevention techniques in order to reduce or eliminate their spills. If the fine levels fall below the cost of preventing the occurrence of the spill, it is probable that the organizations affected will elect to run the risk of paying a penalty and the influence of the fine schedule will be negligible. On the other extreme, if the fine levels are exorbitantly high, the companies will in all likelihood be either forced out of business or into the courts. However, if the fines equal or just exceed the cost of preventing the spill, positive action on the part of the affected organizations can be expected and the number and quantity of spills will most likely be reduced. In such a case, the implemented methodology would

be successful in approaching the expressed goal of the law...no spills of hazardous materials.

The intent of this methodology is to equate the penalty assessed a spiller to the cost of preventing the spill. In order to derive the cost of prevention, trade organizations (Manufacturing Chemists Association, Association of American Railroads, Truck Trailer Manufacturing Association, National Tank Truck Carriers, Inc., Department of Transportation) as well as individual industrial firms, were contacted to provide information concerning the best means of preventing spills, the cost of such prevention techniques, the efficiency of the techniques in preventing spills, and the secondary costs which may occur due to the implementation of the prevention techniques (the individual industrial firms have requested to remain anonymous). The data supplied by the preceding organizations and their member firms were compiled to develop a cost of prevention for stationary sources and two transportation sources (rail and barge).

During the course of the methodology development, it became apparent that the cost of prevention was unrelated to the toxicity, dispersion, or degradation characteristics of the substance. However, the cost was a function of the substance's corrosiveness or flammability. Consequently, prevention costs have been developed along these lines.

For each source classification (e.g., transportation) and sub-classification (e.g., rail and barge) numerous prevention techniques or methods exist or have been proposed. In order to reduce the complexity of developing a cost of prevention for a source of discharge, it became apparent that a single prevention technique would have to be selected upon which a single cost could be developed. The selection was based upon the prevention technique which has received the greatest use or recognition as being effective by those organizations which responded to the authors' initial request for information. The resulting cost of prevention presented here is based upon the single prevention technique, or combination of techniques, described.

The cost of prevention has been defined for the purpose of the study as the total annualized capital and operating costs involved in equipment, structures, engineering fees, and manpower which are solely directed to the prevention of a discharge of hazardous material. The efficiency of the prevention techniques is expressed as the percent of the total production which is prevented from being spilled by the instigated techniques or, in other words, the quantity of material prevented from being spilled. Hence, the return on investment realized by an organization for its efforts is equivalent to the ratio (dollars/quantity) of the preceding two figures. For this methodology,

the rate of penalty is equal to the dollars spent on spill prevention equipment per unit quantity prevented from being spilled.

All of the cost of prevention figures are based upon data provided by only a small percentage of the organizations producing or transporting hazardous materials. Because of the small sample that responded to the request for data, the cost figures may require adjustment at a later date when more complete information becomes available. The development of the cost of prevention figures is discussed for each classification below.

Stationary Sources

The cost of prevention for stationary sources has been based upon spill containment equipment and structures. These facilities include dikes, levees, drainage ditches, sewers, sumps and pumps, weirs, holding tanks or ponds, monitoring equipment, roofs over process areas (to reduce the collection of rainwater), valves, concrete pads, and other similar devices. A detailed discussion of prevention measures and equipment can be found in Goodier, et al.⁴³ The data collected reflect the cost of installing equipment similar to the preceding, and the effectiveness of such installations.

Two major manufacturers of chemicals and their byproducts responded to the authors' inquiries. The data received indicated a mixture of containment schemes but similar overall prevention costs.

Data received from one of the companies indicated a cost differential between corrosive or flammable substances and others. The cost differential reflects the added costs of utilizing more resistant construction materials and extra precautions for the former substances. This company indicated that over a two and one half year period, the reduction of spillage of materials averaged 24.26 m³ per year (6400 gallons per year). Since the figure represented a mixture of materials, an average specific gravity of 1.0 has been assumed. Hence, the quantity of material prevented from being spilled is equivalent to 24,260 kg (53,480 lbs) per year.

The cost of prevention for noncorrosive, nonflammable substances, as reported by this company, was \$1 x 10⁶, which annualized over a 15 year life (as reported by industry) at 12 percent amounts to \$147,000. Hence, the cost of prevention is equivalent to

$$\text{Cost of Prevention} = \frac{\$147,000/\text{year}}{24,260 \text{ kg/year}} = \$6.07/\text{kg} (\$2.75/\text{lb})$$

⁴³Goodier, I. L., J. I. Stevens, S. V. Marqolin, W. V. Keany and J. R. McMalian. "Spill Prevention Techniques for Hazardous Polluting Substances," EPA, OHM 7102 001, February 1971.

The 12 percent annual interest rate is based upon the assumption that management would elect to place their firm's money into profit-making ventures if the modifications were not undertaken and that current and forecasted interest rates justify a rate of this level.

The cost of prevention for corrosive or flammable substances, as reported by this company, is $\$2. \times 10^6$, which annualized over a 15 year life at 12 percent amounts to \$294,000. Hence, the cost of prevention is

$$\text{Cost of Prevention} = \frac{\$294,000/\text{year}}{24,260 \text{ kg/year}} = \$12.14/\text{kg} (\$5.50/\text{lb})$$

Hence, the average cost for both types of substances is \$9.11/kg (\$4.13/lb).

Data received from the other respondent indicated that the cost for the installation of a complete plant spill prevention system was $\$3 \times 10^6$. This system of drainage lines, sumps, pumps, weirs, valves, and holding ponds prevented the spillage of 379 m³ (100,000 gallons) of material over a seven year period. The average specific gravity of the material produced at the plant is 0.997. Hence, the total quantity of material contained is equivalent to 376,935 kg (831,000 lbs). This figure converts to an annual rate of 53,880 kg/year (118,785 lbs/year).

The estimated life of the equipment and drainage system is 25 years (as reported by the company). Therefore, at a 12 percent interest rate, the capital recovery factor equals 0.127 and the annualized capital cost of \$381,000. The operating and maintenance cost averaged (during this seven year period) one percent of the initial capital investment (or \$30,000) and the annual sampling and analyses costs were \$50,000. Therefore, the total annual expenditures are \$461,000. Hence, the cost of prevention for this complete containment is

$$\frac{\$461,000}{53,879 \text{ kg}} = \$8.56/\text{kg} (\$3.88/\text{lb})$$

Since the above plant processes both corrosive and noncorrosive materials, this cost of prevention already represents an average between the two classes of substances.

The average overall stationary source cost of prevention (based upon these two inputs) is \$8.82/kg (\$4.00/lb).

Non-Stationary Sources

Barge. The cost of prevention for barge transportation has been based upon vessel design modifications. Specifically, the individual unit cost of prevention for a barge was based upon

the cost of utilizing double-hulled Type III barges in place of single-hulled Type III barges. The barge size classification was 59 m x 10.7 (195' x 35') with a capacity of 1134 metric tons (1250 tons).

Type III barges are designed to carry products of sufficient hazard to require a moderate degree of control (e.g., acetic acid, hydrochloric acid, sulfuric acid). Each barge must meet certain specific standards of watertight subdivision, structural hull strength, and tank arrangement to protect the cargo against uncontrolled loss as a result of grounding, collision, or sinking.

Single-skin barges, in general, consist of a formed shell. These barges have bow and stern compartments separated from the midship by transverse collision bulkheads. The entire midship shell of the vessel constitutes the cargo tank. Internal hydrodynamic considerations require the tank to be divided by bulkheads.

Double-skin barges have an inner and outer shell. The inner shell forms cargo tanks free of appendages which facilitates cleaning and lining. There is a void between tank (inner shell) and barge hull (outer shell).

The single-skin Type III barge cost was estimated (by industry) at \$176,000 and the double-skin Type III at \$200,000. The equipment has a depreciated life of 14 years and an annual maintenance cost of 4.5 percent, as reported by industry. The capital recovery factor for a 14 year life at 12 percent annual interest is 0.152.

A loss of cargo of 0.0144 percent during a four and one half year period was reported by one of the responding industries presently using double-hulled barges. This company estimated that had single-skin barges been in use, their losses would have been 0.05 percent. Thus, a 0.0356 percent reduction in cargo loss due to spill can be projected for the conversion from single- to double-hulled vessels. Since the capacity of the model barge was 1.13×10^6 kg (2.5×10^6 lbs), the quantity of material prevented from being spilled would be 1.13×10^6 kg x 0.000356, which is equivalent to 402 kg (887 lbs). The cost of prevention per barge would be

$$\text{Capital Cost} = \$200,00 - \$176,00 = \$24,000$$

$$\text{Annualized Capital Cost @12\%} = \$24,000 \times 0.152 = \$3,648/\text{year}$$

$$\begin{array}{l} \text{Operating and Maintenance Cost} \\ \text{Increase} \end{array} = \$24,000 \times 0.045 = \$1,080/\text{year}$$

$$\text{Annual Total Cost of Prevention} = \$4,728/\text{year}$$

Therefore, the cost of prevention for the barge industry would be

$$\text{Cost of Prevention} = \frac{\$4728/\text{year}}{402 \text{ kg/year}} = \$11.76/\text{kg} (\$5.35/\text{lb})$$

Railroads. The cost of prevention for the railroad industry can be based upon tank car modifications. This would include the cost of tank car modifications and the secondary costs involved in switching from one type of tank car to another (for instance, tariff cost differentials or equipment obsolescence losses).

Equipment modifications are effective in reducing derailments or spills caused by mechanical failures and minimizing losses in the case of derailments resulting from other causes. Inherent in the development of this methodology is the assumption that such modifications will be 100 percent effective in reducing these types of failures. If all modifications were incorporated and equipment maintained, the realization of 100 percent reduction in spills due to this cause would be approached (but, of course, never reached).

Data received from shippers of hazardous materials indicated that over a tank car's lifetime (20-25 years), each car has a 50 percent chance of being involved in a derailment. Of all these derailments, 17 percent result in a spill of material. Hence, during the lifetime of a tank car, an 8.5 percent (.17x.50) chance of spilling any of its contents exists.

For an average parathion tank car of 45.5 m³ (12,000 gallons) capacity, the reduction in the amount spilled over the lifetime of the equipment would be 8.5 percent of 45.5 m³ or 3.87 m³ (1020 gallons). The cost of modifying the parathion tank car would be \$1835 over the life of the equipment and would include \$353 for head shields and \$1500 for installation of type F couplers. The F coupler has the potential, when mated with another F coupler, to protect the car against head punctures.* Therefore, the cost of prevention is \$1835/4523 = \$0.41/kg (\$0.18/lb) for parathion. For a substance such as phenol, the 87.2 m³ cars (23,000 gallons) should be converted from internally coiled to externally coiled in addition to the other modifications. This would add \$8250 to the costs for a total of \$8250 + \$1853 or \$10,085. In this case, the cost of prevention would be \$10,085/(87 m³ x 8.5 percent) = \$1.27/kg (\$0.57/lb). Averaging the two, the cost of prevention for rail transportation is \$0.84/kg (\$0.37/lb).

*A recent study by RPI-AAR indicated the "E" couplers may be preferable over "F" couplers.**

**Philips, E. "Final Phase 10 Report on Couplers and Truck Securement," Railroad Tank Car Safety Research and Test Project, September 9, 1972.

The preceding costs are based on the assumption that head shields and F couplings will minimize tank car spills to a point which is insignificant compared to present levels. This, of course, is a generalization. The protection of appurtenances (fill and drain spouts) would help increase the reliability of this assumption. However, no cost estimates are available at this time for such measures. If the cost of these modifications is relatively small, the values calculated here should hold.

No attempt has been made to cost out modifications for hopper or box cars. Spill data received from an AAR member firm indicates that spills of materials transported in these cars are insignificant when compared to spills from tank cars. Further, since many of these substances are solid materials, the likelihood of spills leading to contamination of navigable waters is small.

Trucking. Insufficient data was available to estimate an independent cost of prevention for spills from trucks. Of the accidents that have been reported, 95 percent have involved spillage at loading and unloading facilities.¹ These latter incidences would qualify as stationary source spills and, consequently, the cost of prevention for spills from trucks has been equated to that for stationary sources.

It has been suggested that spills from trucks themselves could largely be prevented if valves and other appurtenances were provided ample shielding. However, no data were found which reports the cost or effectiveness of these measures.

Base Rate of Penalty

From the preceding data, the base rate of penalty for this methodology is assumed to be equivalent to the cost of prevention. Table VII-4 summarizes these penalties.

TABLE VII-4
BASE PENALTY FOR VARIOUS SOURCES

<u>Source</u>	<u>Base Penalty Rate</u>
<u>Fixed Facility</u>	
Plants	\$ 8.82/kg (\$4.00/lb) [p. II-123]
<u>Transportation</u>	
Barge	\$11.76/kg (\$5.35/lb) [p. II-125]
Rail	\$ 0.84/kg (\$0.37/lb) [p. II-127]

The preceding penalty levels are based upon only a small portion of the affected industries and, therefore, their statistical significance cannot be asserted at this time (although some of the data indicates significant similarities between the individual costs of prevention for the reporting industries). It is difficult from the data received to clearly state that the costs are below average, about average, or average for industry as a whole. However, it can be asserted that the cost data provided was developed from normal prevention techniques and that more exotic and fail-safe techniques would increase the cost. It can be further stated that hazardous materials with the potential to inflict significant levels of harm (as indicated by their toxicity, solubility, and dispersal characteristics) should be more carefully handled and controlled. In order to incorporate such incentives in the rate of penalty, a method to adjust the base rate of penalty according to a substance's characteristics has been devised.

Adjustment Factor

It is recognized that the physical characteristics of many materials will prevent rapid dilution to threshold concentrations or may allow for removal or destruction of much of the material prior to the occurrence of harm and vice versa.

Section 311(b)(2)(B)(iv) clearly states that the penalty imposed upon a spiller of a particular hazardous material should reflect the toxicity, degradability, and dispersal characteristics of the substance and that the penalty charged to all spillers (per unit of measure) must vary within an order of magnitude.

In order to reflect the different characteristics of each hazardous material, several factors have been developed to incorporate the aforementioned characteristics.

Dispersion - Solubility Factor

The actual level of harm inflicted by a substance is a function of the surrounding environmental conditions and the characteristics of the material in water. The solubility of a substance reflects its ability to dissolve into the water body and reach a toxic concentration level. By the selection criteria utilized, substances designated hazardous have solubilities in excess of reported toxicity levels. Since advective and diffusive forces will be acting to disperse the hazardous material once spilled into a water body, the ratio of the substance's solubility to its toxicity is a good indicator of the size of the potential kill zone formed. The larger this ratio becomes, the greater the quantity of water contaminated to the toxic level by the spill and, hence, the greater the potential for harm. A high ratio infers that the solubility of the substance is substantially

larger than its mean toxicity level which indicates that a large plug of greater than toxic concentration is likely to occur. Naturally, the potential for damage to occur is high. On the other hand, a low ratio of solubility to toxicity would imply that a very small, localized plug of contaminated waters will be formed and the potential for harm is significantly lower than in the previous case (Figure VII-8).

In order to reflect the preceding relationship, the following factor has been developed by the authors:

$$D_1 = \left(1 - \frac{1}{1 + \log \frac{SOL}{CC}} \right)$$

D_1 = dispersion-solubility term

SOL = solubility of the substance, mg/l

CC = critical concentration of the substance, mg/l (The toxicity is not adjusted to the 6 hour LC₅₀ since this would only introduce another constant--the application factor S--to the formulation. D_1 is only a measure of relative dispersibility so constants are eliminated.)

Figure VII-9 indicates how the dispersion-solubility term varies with an increasing or decreasing solubility-to-mean-toxicity ratio. For the substances presently under investigation, the range of D_1 is between 0 and approximately 0.87.

Toxicity Factor

A second indicator of the potential level of harm is relative toxicity. A substance which is highly toxic to aquatic organisms (concentration at which the substance is toxic is low) has a greater potential to induce harm than a substance with a low toxicity (concentration at which the substance is toxic is high). All the methodologies utilized in this procedural formulation have incorporated the mean toxicity level as the toxicity criteria and it is recognized that a spill of a highly toxic substance is likely to form a plug of substantially greater concentration than that required for 50 percent fatality among the receptor organisms.

In order to reflect the different potential levels of harm for each substance, the following factor was devised by the authors:

$$T = \left(1 - \frac{1}{1 + \log \frac{500}{CC}} \right)$$

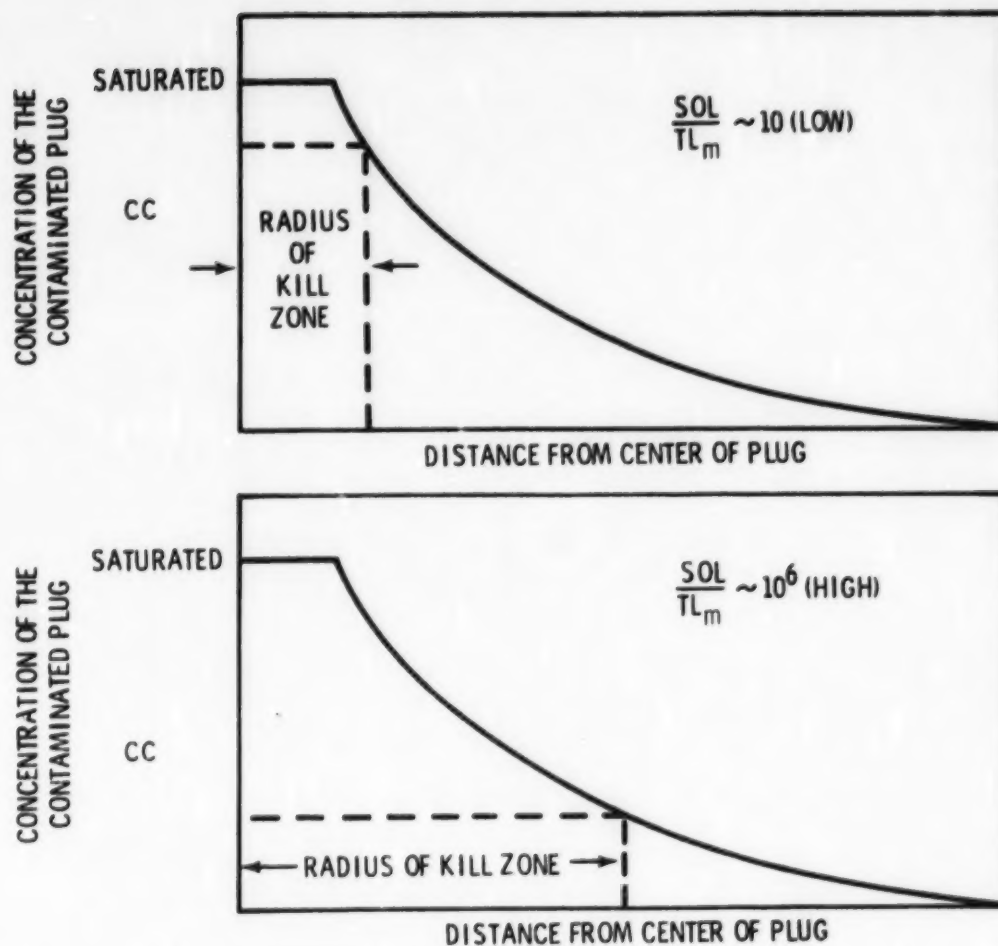


FIGURE VII-8. RELATIVE CHANGE IN POTENTIAL KILL ZONE WHEN MATERIALS OF EQUAL SOLUBILITY HAVE GREATLY DIFFERENT CRITICAL CONCENTRATIONS

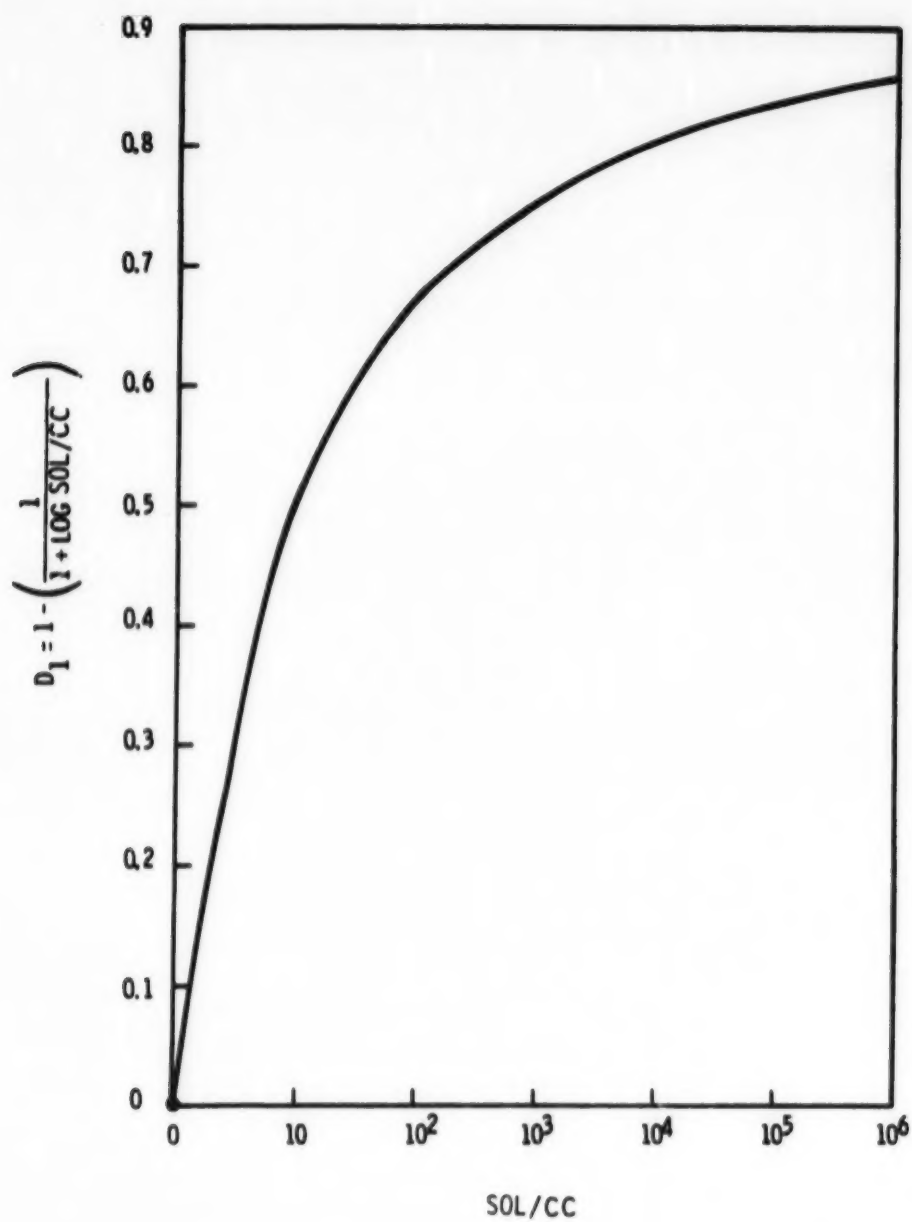


FIGURE VII-9. RESPONSE OF THE DISPERSION-SOLUBILITY ADJUSTMENT TERM TO CHANGES IN THE SOL/CC RATIO

T = toxicity factor

CC = critical concentration, mg/l (As stated earlier, the adjustment factors are relative. Thus there is no need to convert toxicity to the 6 hour LC₅₀ value.)

500 = 500 mg/l, maximum toxicity level utilized in designating a substance as being hazardous.

Figure VII-10 indicates how the toxicity factor varies with changes in the mean toxicity of various substances. For the substances presently designated as hazardous, the range of T varies between 0 and approximately 0.82. The factor approaches zero as the critical concentration approaches 500. Materials with critical concentrations >500 mg/l are given a value of T = 0. This may occur for substances selected on the basis of oral or dermal or other criteria than direct lethality to aquatic life.

Degradability Factor

The degradability factor reflects the environmental half-life of the substance. A material which, upon entry into the water body, rapidly decays due to bacterial or chemical action, poses a smaller hazard to aquatic organisms than a substance which is persistent. An assumption has been made that as material is degraded, less is available as a contaminant and thus the effective spill size is reduced.

$$D_2 = 1 - \text{DEG}$$

where D_2 = degradability factor, and

DEG = estimated loss in four day period.

Thus, if biochemical oxidation is the mode of degradation, DEG equals the fractional theoretical BOD₄ since the four day BOD corresponds to the maximum plug duration of 96 hours. The conversion from BOD₅ is

$$\text{BOD}_4 = 0.88 \text{ BOD}_5$$

(The four-day period was selected to be consistent with the 96 hour base exposure time employed. The conversion of the plug flow model to a six-hour time of passage through use of the application factor, (S), is designed solely to determine harmful quantity and does not apply here.) The characteristic of the degradability curve is illustrated in Figure VII-11. The degradability factor varies between 0 and 1.0.

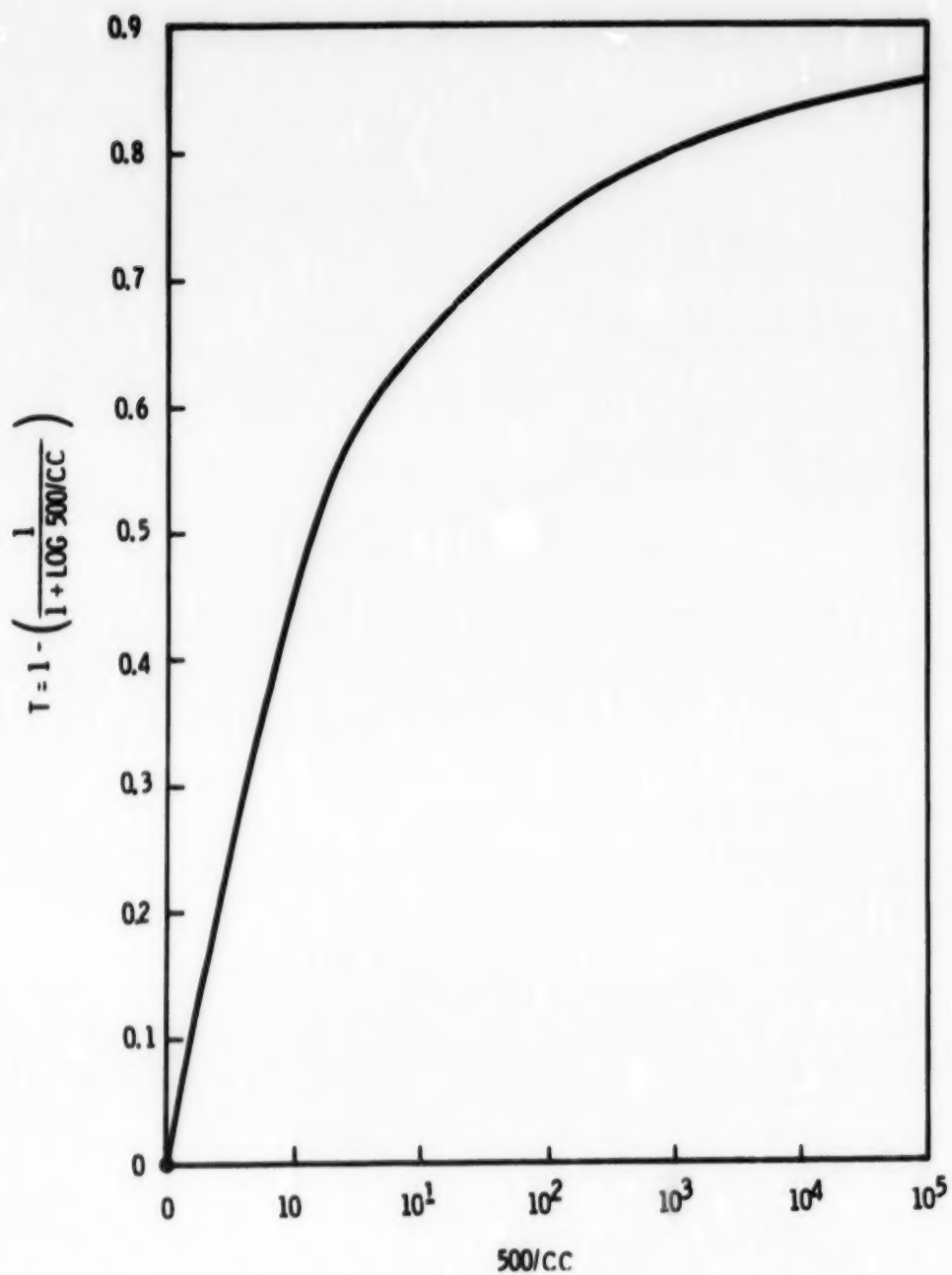


FIGURE VII-10. RESPONSE OF THE TOXICITY ADJUSTMENT FACTOR TO CHANGES IN THE 500/CC RATIO

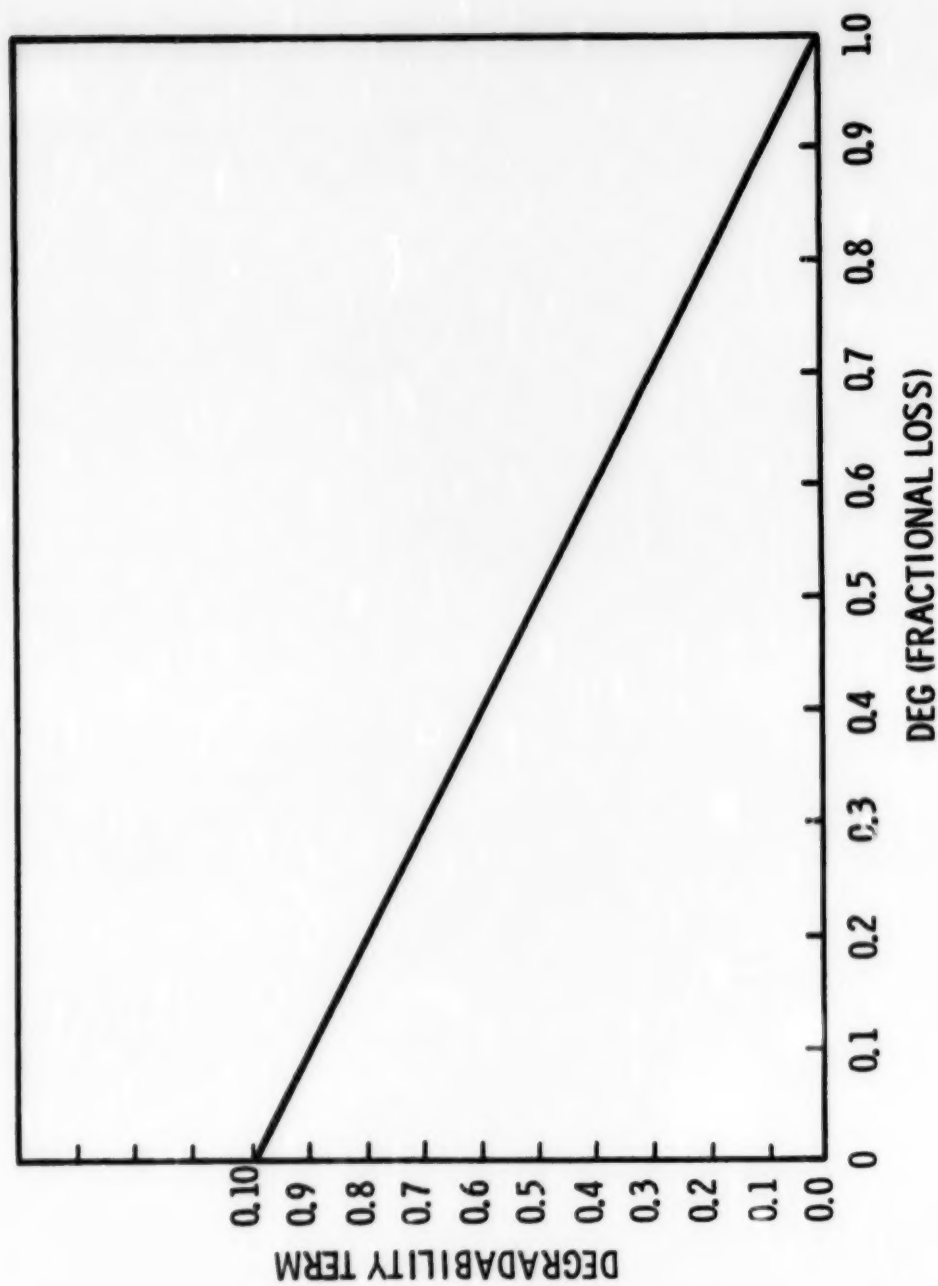


FIGURE VII-11. RESPONSE OF THE DEGRADABILITY ADJUSTMENT TERM TO VARIATION IN THE FRACTIONAL LOSS CHARACTERISTIC

It can be argued that each term's ability to describe the potential inducement of harm by a substance is not equivalent and subsequently each term should be considered independently. However, data are not sufficient to indicate the importance of one term over another. Therefore, the preceding three factors are viewed as multiplicative.

It must be emphasized here that no attempt is being made to quantify natural laws. The factors described above are merely operators designed to compare relative potential harm.

With the multiplicative assumption, the total function reflecting the substance's dispersion, toxicity, and degradability characteristics takes the following form:

$$Y_0 = \left(1 - \frac{1}{1 + \log \frac{SOL}{CC}}\right) \left(1 - \frac{1}{1 + \log \frac{500}{CC}}\right) (1 - DEG)$$

and the term varies between 0 and approximately 0.71.

A substance which has a high solubility to toxicity ratio and is highly toxic but decays readily is most likely to have a low impact upon the aquatic life of the water body. Similarly, a low value for the other factors will drive the product value down. Data presented in Table VII-5 have been developed to indicate the expected impacts occurring from the various combinations of the preceding parameters.

TABLE VII-5

EFFECT OF THE SUBSTANCE'S CHARACTERISTICS
UPON THE ADJUSTMENT FACTOR

<u>Solubility to Toxicity Ratio</u>	<u>Toxicity Level</u>	<u>Environmental Half-life</u>	<u>Impact</u>
0.87	0.82	1.0	0.71
0.87	0.82	<0.5	0.36
0.87	<0.41	1.0	0.36
0.87	<0.41	<0.5	<0.18
<0.43	0.82	1.0	<0.35
<0.43	<0.41	1.0	<0.18
<0.43	0.82	<0.5	<0.18
<0.43	<0.41	<0.5	<0.09

It must be reemphasized here, that no attempt is being made to characterize a new set of natural laws. These relations are merely designed as operators to reflect the tendencies for certain physical properties to enhance or retard a material's ability to exert its hazard potential.

As previously indicated, Section 311(b)(2)(B)(iv) allows the administrator the flexibility of varying the base penalty rate over an order of magnitude depending upon a substance's behavior in a water body. However, the rate of penalty for the DOHM Methodology is based upon the average cost of prevention for those reporting industries. The data received from industry indicates a cost differential of approximately two exists for preventing the occurrence of spills depending upon whether or not a substance is highly flammable or corrosive. The additional measures required to prevent spills of highly flammable or corrosive substances are expected to be similar to those necessary to prevent the discharge of highly toxic substances and hence, a variance from the base rate of penalty by a factor of two is appropriate. In other words, while the handler of extremely hazardous substances should be motivated to install prevention systems in excess of the industrial "average," the incentive should not exceed twice the average cost of prevention. The total adjustment factor (rk) is therefore reduced to the following form:

$$rk = 1 + f [(D_1) (T) D_2]$$

where rk = penalty rate adjustment factor, and

$$f = 1/0.71 = 1.41.$$

Since the term $(D_1) (T) (D_2)$ varies between 0 and 0.71, rk will vary between 1 and 2 and therefore penalties will range between the cost of prevention and twice the cost of prevention. Rk adjustment factors are tabulated for designated hazardous substances in Appendix M.

The cost of prevention is converted to the penalty rate imposed upon a spiller for the DOHM Methodology by multiplying the cost of prevention by each substance's rk value. Example calculations are presented in Table VII-6 for spills in freshwater (rivers and lakes). Rates of penalty and harmful quantities resulting from utilization of the DOHM Methodology on designated hazardous substances are compared to those for the three alternative methodologies in Appendix N. It is apparent that if the prevention incentive reviewed and adjusted periodically to reflect changes in prevention costs/technology and/or monetary fluctuations.

TABLE VII-6
EXAMPLE CALCULATIONS OF FINAL RATES OF PENALTY FOR SPILLS IN FRESHWATER

Chemical	CC* (mg/l)	Basis	Solubility S, mg/l	BOD ₅ [†]	Freshwater rk
Acetaldehyde	53.0	TL _{m96} sunfish	>1,000,000	93 1.27 lb/lb	1.11
Phenol	13.5	TL _{m96} bluegill	67,000	75 1.7-2 lb/lb	1.28
Cadmium sulfate	5.6	TL _{m96} fathead minnows	755,000	0	1.72

*Critical concentration

†Degradation (% theoretical)

Source	Chemical	Base Penalty Rate	Adjusted Penalty Rate
Plants	Acetaldehyde	\$ 8.82/kg (\$4.00/lb)	\$ 9.78/kg (\$ 4.50/lb)
	Phenol	\$ 8.82/kg (\$4.00/lb)	\$11.29/kg (\$ 5.12)
	Cadmium sulfate	\$ 8.82/kg (\$4.00/lb)	\$16.00/kg (\$ 7.10)
Barge	Acetaldehyde	\$11.76/kg (\$5.35/lb)	\$13.02/kg (\$ 5.91/lb)
	Phenol	\$11.76/kg (\$5.35/lb)	\$15.05/kg (\$ 6.83)
	Cadmium sulfate	\$11.76/kg (\$5.35/lb)	\$21.00/kg (\$ 9.50)
Rail	Acetaldehyde	\$ 0.84/kg (\$0.37/lb)	\$.93/kg (\$.41/lb)
	Phenol	\$ 0.84/kg (\$0.37/lb)	\$ 1.08/kg (\$.47)
	Cadmium sulfate	\$ 0.84/kg (\$0.37/lb)	\$ 1.50/kg (\$.68)

REFERENCES

1. U. S. Department of Transportation, Office of Hazardous Materials. "Reports of Spills of Hazardous Substances: Computer File," as abstracted by Mr. Robert Reese, National Tank Truck Carriers, Washington, DC.
2. U. S. Environmental Protection Agency, Division of Oil & Hazardous Materials. "The DOHM Approaches," Annex to RFP WA74-R064 distributed at Bidder's Conference, November 6, 1973.
3. "Pollution-Caused Fish Kills in 1960," U. S. Department of Health, Education, and Welfare; Public Health Service, 1960.
4. "Pollution-Caused Fish Kills January-September 1961," U. S. Department of Health, Education, and Welfare; Public Health Service, Washington, DC, November 1961.
5. "Pollution-Caused Fish Kills in 1963," U. S. Department of Health, Education, and Welfare; Public Health Service, Washington, DC, 1963.
6. "Pollution-Caused Fish Kills in 1964," U. S. Department of Health, Education, and Welfare; Public Health Service, Washington, DC, 1964.
7. "Pollution-Caused Fish Kills in 1965," U. S. Department of the Interior, Federal Water Pollution Control Administration, Washington, DC, 1965.
8. "Fish Kills by Pollution in 1966," U. S. Department of the Interior, Federal Water Pollution Control Administration, Washington, DC, 1966.
9. "Pollution-Caused Fish Kills in 1968," U. S. Department of the Interior, Federal Water Pollution Control Administration, Washington, DC, 1967.
10. "Pollution-Caused Fish Kills in 1968," U. S. Department of the Interior, Federal Water Pollution Control Administration, Washington, DC, 1968.
11. "1969 Fish Kills Caused by Pollution," Federal Water Quality Administration, USGPO, Washington, DC, 1970.
12. "Fish Kills Caused by Pollution in 1970," U. S. Environmental Protection Agency, USGPO, Washington, DC, 1972.
13. Calamori, D. and R. Marchetti. "The Toxicity of Mixtures and Surfactants to Rainbow Trout (Salmo gairdneri Rich.), Water Research, Vol. 7, 1973.

14. Herbert, D. W. M. and J. C. Merkins. "The Toxicity of Potassium Cyanide to Trout," J. Exp. Biol., Vol. 29, pp. 632-649, 1952.
15. Abram, F. S. H. "The Definition and Measurement of Fish Toxicity Thresholds," Advances in Water Pollution Research, Proc. 3rd International Conference held in Munich, Germany. WPCF, Washington, DC, Vol. 1, pp. 75-95, September 1966.
16. Abram, F. S. H. "An Application of Harmonics to Fish Toxicology," J. Air & Water Pollution, Vol. 8, pp. 325-338, 1964.
17. Herbert, D. W. M. and D. S. Shurben. "The Toxicity of Fluoride to Rainbow Trout," J. Water & Waste Treatment, Vol. 10, pp. 141-142, 1964.
18. Swedmark, M., B. Braaten, E. Emanuelsson and A. Granmo. "Biological Effect of Surface Active Agents on Marine Animals," Marine Biology, Vol. 9, pp. 183-201, 1971.
19. Fletcher, G. L. and R. J. Hoyle. "Acute Toxicity of Yellow Phosphorus to Atlantic Cod and Atlantic Salmon Smolts," J. Fish. Res. Bd. Can., Vol. 29, No. 9, pp. 1295-1301, 1972.
20. Alderdice, D. F. and M. E. Worthington. "Toxicity of a DDT Forest Spray to Young Salmon," Can. Fish Culturist, Vol. 24, pp. 41-48, 1959.
21. "Acute Toxicity of Heavy Metals to Some Marine Larvae," Marine Pollution Bulletin, Vol. 3, No. 12, December 1972.
22. Brown, V. M. and R. A. Dalton. "The Acute Toxicity to Rainbow Trout of Mixtures of Copper, Phenol, Zinc and Nickel," J. Fish. Biol., Vol. 2, pp. 211-216, 1970.
23. Brown, V. M., D. H. M. Jordan and B. A. Tiller. "The Acute Toxicity to Rainbow Trout of Fluctuating Concentrations and Mixtures of Ammonia, Phenol and Zinc," J. Fish. Biol., Vol. 1, pp. 1-9, 1969.
24. Sprague, J. B. and B. A. Ramsay. "Lethal Levels of Mixed Copper-Zinc Solutions for Juvenile Salmon," J. Fish. Res. Bd. Can., Vol. 22, No. 2, pp. 425-532, 1965.
25. Sprague, J. B. "Lethal Concentrations of Copper and Zinc for Young Atlantic Salmon," J. Fish. Res. Bd. Can., Vol. 21, No. 1, pp. 17-26, 1964.
26. Lloyd, R. and D. H. M. Jordan. "Some Factors Affecting the Resistance of Rainbow Trout (Salmo gairdneri) to Acid Waters," J. Air & Water Pollution, Vol. 8, pp. 292-403, 1964.

27. Herbert, D. W. M. and D. S. Shurben. "The Toxicity to Fish of Mixtures of Poisons, I. Salts of Ammonia on Zinc," Ann. Appl. Biol., Vol. 53, pp. 33-41, 1964.
28. Brown, V. M., D. H. M. Jordan and B. A. Tiller. "The Effect of Temperature on the Acute Toxicity of Phenol to Rainbow Trout in Hard Water," Water Research, Pergamon Press, Vol. 1, pp. 587-594, 1967.
29. Herbert, D. W. M. "Pollution and Fisheries," Ecology and the Industrial Society, Fifth Symposium of the British Ecological Society, Blackwell Scientific Publications, 1965.
30. Wuhrmann, K. "Concerning Some Principles of the Toxicology of Fish," J. Fish. Res. Bd. Can., Translation Series No. 243, August 1959.
31. Alabaslor, J. S. and F. S. H. Abram. "Development and Use of a Direct Method of Evaluating Toxicity to Fish," Advanced Water Pollution Research, Proc. 2nd International Conference held in Tokyo, Japan in August 1964, Vol. 1, 1965.
32. Ball, I. R. "The Relative Susceptibilities of Some Species of Freshwater Fish to Poisons, I. Ammonia," Water Research, Pergamon Press, Vol. 1, 1967.
33. Personal communication, Dr. A. L. Jennings, USEPA/Hazardous and Toxic Substances Branch, Division of Technical Standards. Unpublished data, July 24, 1974.
34. McKee, J. E. and H. W. Wolf. "Water Quality Criteria," HEW/USPHS, The Resources Agency of California and the State of California Water Resources Control Board, Publication 3-A, April 1971.
35. Sprague, J. B. "Measurement of Pollutant Toxicity to Fish, III. Sublethal Effects and 'Safe' Concentrations," Water Research, Vol. 5, pp. 245-266, 1971.
36. Pritchard, D. W. "Dispersion and Flushing of Pollutants in Estuaries," ASCE, Hydraulics Division, pp. 115-124, January 1969.
37. Pritchard, D. W. "Estuarine Circulation Patterns," ASCE, Hydraulics Division, pp. 717-1 - 717-11, June 1955.
38. Burt, W. V. and W. B. McAlister. "Recent Studies in the Hydrography of Oregon Estuaries," Research Briefs, Fish Commission of Oregon, Vol. 7, No. 1, pp. 14-27, July 1959.
39. Simmons, H. B. "Field Experience in Estuaries," Estuary and Coastline Hydrodynamics, McGraw-Hill, pp. 673-690, 1966.

40. Pritchard, D. W. "Observations of Circulation in Coastal Plain Estuaries," Estuaries, American Association for the Advancement of Science, pp. 37-51, 1967.
41. Fisher, H. B. "Affidavit Concerning Section 307," for the U. S. Environmental Protection Agency.
42. "National Estuarine Pollution Study," a report to the 91st Congress by the Secretary of the Interior pursuant to Public Law 89-753, March 1970
43. Goodier, I. L., J. I. Stevens, S. V. Margolin, W. V. Keany and J. R. McMalian. "Spill Prevention Techniques for Hazardous Polluting Substances," EPA, OHM 7102 001, February 1971.
44. Philips, E. "Final Phase 10 Report on Couplers and Truck Securement," Railroad Tank Car Safety Research and Test Project, September 9, 1972.

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